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SUBSURFACE STRATIGRAPHY OF KETTLEMAN HILLS OIL FIELD, CALIFORNIA[1]

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ABSTRACT

A comparative microscopic study of well cores at Kettleman Hills, and of cores and surface sections in adjacent areas, is presented. Relations between formations penetrated at Kettleman Hills, and variations in lithology and thickness within the area, are discussed. The Kettleman Hills section is correlated with sections at North Coalinga, Reef Ridge, Lost Hills, North Belridge, Belridge, and Gould Hills.

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Introduction

The Kettleman Hills are near the center of western San Joaquin Valley, in western Fresno and King counties, their northern end lying 10 miles southeast of the Coalinga Eastside oil field. They form an outlying range 25 miles long and 5 wide, striking northwest and southeast parallel with the Kreyenhagen Hills. The crest of the latter is known as Reef Ridge. The structure at Kettleman Hills appears to be

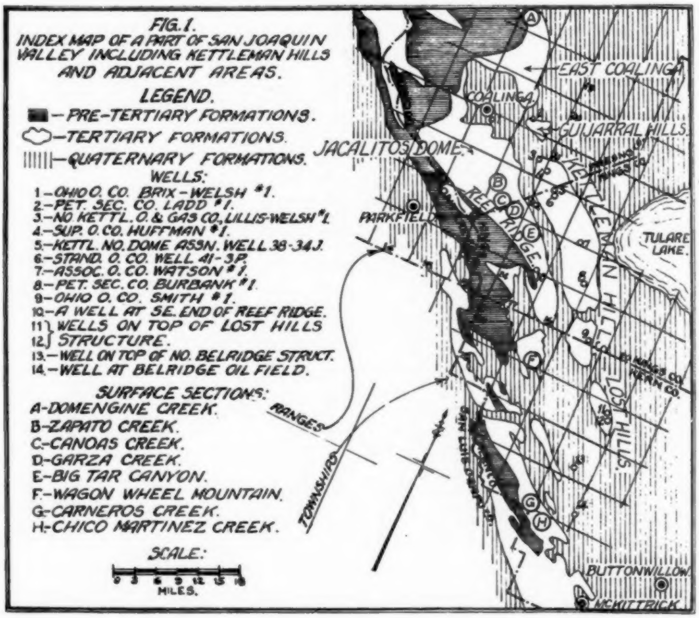

FIG. 1

a continuation of the anticline at the Coalinga Eastside field. It comprises a North, a Middle, and a South dome. The first two are closed. The so-called South "dome" is indicated to be the northwest end of the Lost Hills anticline.

Difficulties.—The general area is a strip lying near the western edge of a Tertiary basin (Fig. 1). This strip was an area of near-shore deposition and erosion during much of the Tertiary, with the result that the lithology and thicknesses penetrated at Kettleman Hills differ considerably from those in some near-by surface sections. Several of the formations in the district have so far failed to furnish re-

mains of the larger marine organisms or of land animals, causing the age of these formations to be a subject of argument. No continuous coring has been done in any well drilled to date, and no well has furnished more than a few samples from the so-called "brown shale." Micro-organisms are present only in a few shaly members of the section, and for considerable thicknesses the assemblages are composed of poorly preserved arenaceous foraminifers. These features cause the present paper to be necessarily a progress report on problems which may not be satisfactorily solved for years.

Material.—The writer has so far examined about 3,000 cores from 47 wells. Of the wells, 4 were on the South, 4 on the Middle, and 39 on the North dome. As regards formations, 12 wells have furnished a good sequence from the so-called "caving blue shale," 13 have furnished fair material from the lower part of the "brown shale," 16 cored nearly continuously through the upper 700–1,000 feet of strata directly underlying the "brown shale," 6 supplied cores from the lower Temblor, and 2 cored older beds.

Parallel examinations have been made of cores from wells at the Lost Hills, North Belridge, and Belridge oil fields, and of surface sections on the McDonald anticline (T. 28 S., R. 19 E.) and in the Gould Hills. This was for the purpose of comparing the Miocene at Kettleman Hills with the Chico Martinez Creek and Carneros Creek sections, which are well exposed and which reveal a remarkably complete Miocene record. As the distance between the Kettleman Hills and the Gould Hills is about 35 miles, the correlation has been by steps, these being Gould Hills, Belridge field, North Belridge field, Lost Hills field, South dome, Middle dome, and North dome of Kettleman Hills, as shown on Figure 1.

The Pliocene, highest Miocene, Oligocene, and upper Eocene exposed record is best obtained on the west and northwest; hence, the writer has expanded his studies west into canyons of the Kreyenhagen Hills, and northwest into the North Coalinga region between Oil City Camp and Domengine Creek. Cores from three wells on the Jacalitos dome, from one at the southeast end of Reef Ridge, and from one near the town of Coalinga, were also examined.

Methods.—Samples were split to afford fresh surfaces, examined under the microscope, and their lithology and organic content noted. The best fragments were then washed. A special method for disintegrating indurated shales has been worked out. The material is crushed in a mortar until smaller than the holders of 20-mesh screen. About 4 cubic inches is then mixed with an equal amount of lye, and boiled in water from 3 to 5 hours. The clay and mud are then flushed out,

the sample reducing to a small residue. A good microfauna has been obtained in this way from hard shales which failed to yield their foraminiferal content by any other method.

In view of the large development of sandy sediments at Kettleman Hills, totaling 60 per cent of the thickness and with few exceptions barren of organic remains, it was desirable to study heavy mineral assemblages in sands. About 9 cubic inches of material was used. After crushing to about the size of the average detrital grains, the samples were boiled in dilute hydrochloric acid for an hour or so, subjected to decantation for removal of cement and mud, dried, and sifted through 80-mesh screen. The portion passing this was then treated with bromoform to separate the heavy minerals.

In order to display the stratigraphic relations between various formations, a series of charts shown as Figures 4, 5, 6, 7, and 8 has been compiled. All columns shown represent true thicknesses. The top of the Gould shale is the datum line. Of the Kettleman Hills wells, only those located close to the surface axis were selected for charting. The composite sections for the Jacalitos dome, and for the Lost Hills, North Belridge, and Belridge fields, have been compiled by combining various wells drilled in these fields.

Stratigraphy

A résumé of the lithology and maximum thicknesses of various parts of the Kettleman Hills section is given in columnar sections shown as Figures 2 and 3. The total thickness of the strata represented by core material is close to 11,500 feet.[3] This series is divided by the writer into Etchegoin (upper Pliocene), Jacalitos (lower Pliocene), McLure shale (late upper Miocene), lower Monterey (early upper Miocene), Temblor and Vaqueros (?) (lower Miocene), upper Kreyenhagen (Oligocene), and lower Kreyenhagen (upper Eocene). Correlation of these divisions with formations at Kettleman Hills recognized by other writers is given in Table I.

PLIOCENE

The division of the Pliocene series adopted in the present paper differs from that by Gester and Galloway chiefly (1) in the retaining of the Etchegoin-Jacalitos contact as recognized by Arnold and Robert Anderson, and (2) in referring the upper part of the so-called "caving blue shale" or Reef Ridge formation to the Jacalitos. This has been done for the following reasons: (1) comparison of the Kettle-

[3] The Pleistocene and uppermost Pliocene formations, from which no cores were obtained, are not included in the composite section, and are not discussed in the present paper.

man Hills subsurface section with the Kreyenhagen area, on the basis of fossiliferous zones, has shown that the Etchegoin-Jacalitos contact of Arnold and Robert Anderson in the Kreyenhagen Hills corresponds with a rather pronounced change in the lithology in wells at Kettleman Hills (Fig. 2); (2) micropaleontological study of the "caving blue shale" reveals that, while the foraminiferal assemblage present in its lower part includes species characteristic of the upper Miocene, the microfaunal content of the upper part of the division is very close to that of the Jacalitos Pliocene.

TABLE I

KETTLEMAN HILLS TERTIARY SECTION

<table>
<tr><th>Age</th><th colspan="3">This Paper</th><th>Gester and Galloway[4]</th><th>Arnold and Anderson[5]</th></tr>
<tr><td rowspan="2">Upper Pliocene</td><td colspan="3">San Joaquin clay</td><td>San Joaquin Clays</td><td rowspan="2">Etchegoin</td></tr>
<tr><td colspan="3">Etchegoin</td><td rowspan="2">Etchegoin</td></tr>
<tr><td>Lower Pliocene</td><td colspan="3">Jacalitos</td><td>Jacalitos</td></tr>
<tr><td rowspan="6">Upper Miocene</td><td rowspan="2">Upper Monterey</td><td rowspan="2">McLure shale</td><td>upper member</td><td>Reef Ridge shale</td><td>Transition zone</td></tr>
<tr><td>lower member</td><td rowspan="3">McLure shale</td><td rowspan="3">Santa Margarita (?)</td></tr>
<tr><td colspan="3">Hiatus</td></tr>
<tr><td rowspan="3">Lower Monterey</td><td colspan="2">"Sporbo" shale</td></tr>
<tr><td colspan="2">Pecten andersoni sand</td><td>Hiatus</td><td>Hiatus</td></tr>
<tr><td colspan="2">Gould shale</td><td rowspan="3">Temblor</td><td rowspan="3">Vaqueros</td></tr>
<tr><td rowspan="2">Lower Miocene</td><td colspan="3">Temblor</td></tr>
<tr><td colspan="3">Vaqueros (?)</td></tr>
<tr><td></td><td colspan="3">Hiatus</td><td>Hiatus</td><td>Hiatus</td></tr>
<tr><td>Oligocene</td><td colspan="3">Upper Kreyenhagen</td><td>Kreyenhagen Group</td><td rowspan="2">Tejon</td></tr>
<tr><td>Upper Eocene</td><td colspan="3">Lower Kreyenhagen</td><td>Domengine</td></tr>
</table>

Etchegoin and Jacalitos (*upper and lower Pliocene*).—The uppermost fossiliferous zone shown in the composite section (Fig. 2, zone A) is that penetrated by the Chanslor-Canfield-Midway Oil Company's McGlashan No. 1 (Sec. 17, T. 24 S., R. 19 E.) between 720 and 970 feet. Samples of clay and sandy clay from this zone have

[4] G. C. Gester and John Galloway, "Geology of Kettleman Hills Oil Field, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 10 (1933), p. 1169, Fig. 3.

[5] Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District, California," *U. S. Geol. Survey Bull. 398* (1910), p. 48.

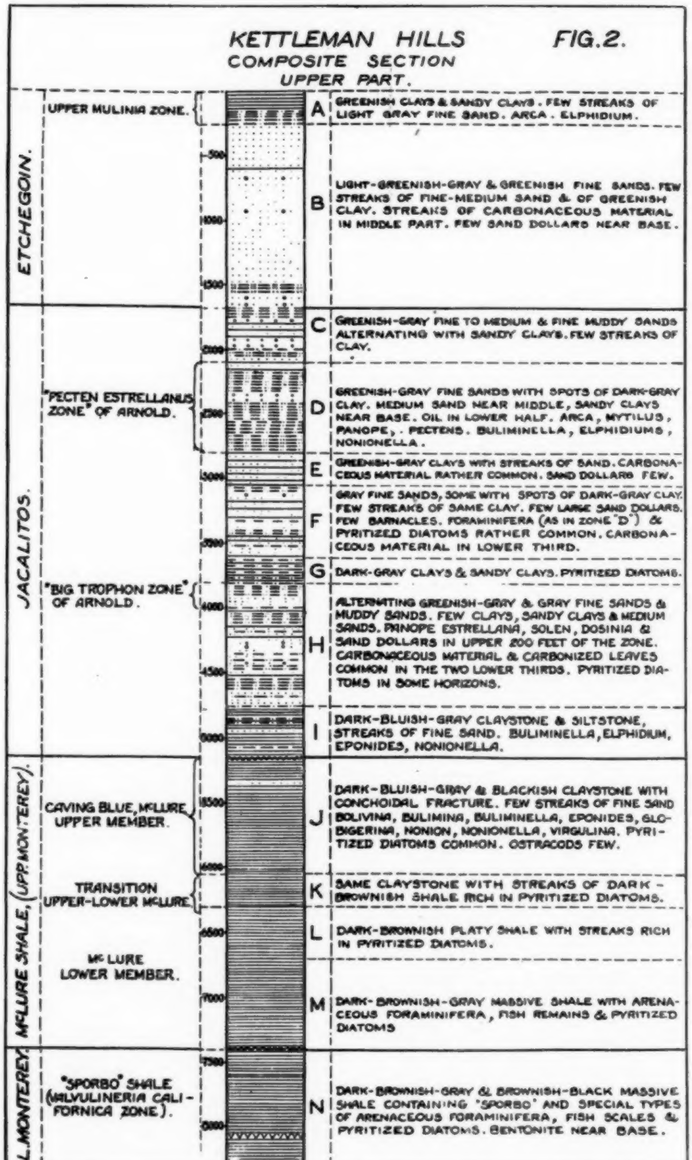
KETTLEMAN HILLS FIG.2.
COMPOSITE SECTION
UPPER PART.
ETCHEGOIN.
JACALITOS.
McLURE SHALE, (UPP. MONTEREY).
L. MONTEREY.
UPPER MULINIA ZONE.
"PECTEN ESTRELLANUS ZONE" OF ARNOLD.
"BIG TROPHON ZONE" OF ARNOLD.
CAVING BLUE, McLURE, UPPER MEMBER.
TRANSITION UPPER-LOWER McLURE.
McLURE LOWER MEMBER.
"SPORBO" SHALE (VALVULINERIA CALIFORNICA ZONE).
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
A GREENISH CLAYS & SANDY CLAYS. FEW STREAKS OF LIGHT GRAY FINE SAND. ARCA. ELPHIDIUM.
B LIGHT-GREENISH-GRAY & GREENISH FINE SANDS. FEW STREAKS OF FINE-MEDIUM SAND & OF GREENISH CLAY. STREAKS OF CARBONACEOUS MATERIAL IN MIDDLE PART. FEW SAND DOLLARS NEAR BASE.
C GREENISH-GRAY FINE TO MEDIUM & FINE MUDDY SANDS ALTERNATING WITH SANDY CLAYS. FEW STREAKS OF CLAY.
D GREENISH-GRAY FINE SANDS WITH SPOTS OF DARK-GRAY CLAY. MEDIUM SAND NEAR MIDDLE, SANDY CLAYS NEAR BASE. OIL IN LOWER HALF. ARCA, MYTILUS, PANOPE, PECTENS. BULIMINELLA, ELPHIDIUMS, NONIONELLA.
E GREENISH-GRAY CLAYS WITH STREAKS OF SAND. CARBONACEOUS MATERIAL RATHER COMMON. SAND DOLLARS FEW.
F GRAY FINE SANDS, SOME WITH SPOTS OF DARK-GRAY CLAY. FEW STREAKS OF SAME CLAY. FEW LARGE SAND DOLLARS. FEW BARNACLES. FORAMINIFERA (AS IN ZONE "D") & PYRITIZED DIATOMS RATHER COMMON. CARBONACEOUS MATERIAL IN LOWER THIRD.
G DARK-GRAY CLAYS & SANDY CLAYS. PYRITIZED DIATOMS.
H ALTERNATING GREENISH-GRAY & GRAY FINE SANDS & MUDDY SANDS. FEW CLAYS, SANDY CLAYS & MEDIUM SANDS. PANOPE ESTRELLANA, SOLEN, DOSINIA & SAND DOLLARS IN UPPER 200 FEET OF THE ZONE. CARBONACEOUS MATERIAL & CARBONIZED LEAVES COMMON IN THE TWO LOWER THIRDS. PYRITIZED DIATOMS IN SOME HORIZONS.
I DARK-BLUISH-GRAY CLAYSTONE & SILTSTONE, STREAKS OF FINE SAND. BULIMINELLA, ELPHIDIUM, EPONIDES, NONIONELLA.
J DARK-BLUISH-GRAY & BLACKISH CLAYSTONE WITH CONCHOIDAL FRACTURE. FEW STREAKS OF FINE SAND BOLIVINA, BULIMINA, BULIMINELLA, EPONIDES, GLOBIGERINA, NONION, NONIONELLA, VIRGULINA. PYRITIZED DIATOMS COMMON. OSTRACODS FEW.
K SAME CLAYSTONE WITH STREAKS OF DARK-BROWNISH SHALE RICH IN PYRITIZED DIATOMS.
L DARK-BROWNISH PLATY SHALE WITH STREAKS RICH IN PYRITIZED DIATOMS.
M DARK-BROWNISH-GRAY MASSIVE SHALE WITH ARENACEOUS FORAMINIFERA, FISH REMAINS & PYRITIZED DIATOMS
N DARK-BROWNISH-GRAY & BROWNISH-BLACK MASSIVE SHALE CONTAINING "SPORBO" AND SPECIAL TYPES OF ARENACEOUS FORAMINIFERA, FISH SCALES & PYRITIZED DIATOMS. BENTONITE NEAR BASE.

FIG. 2

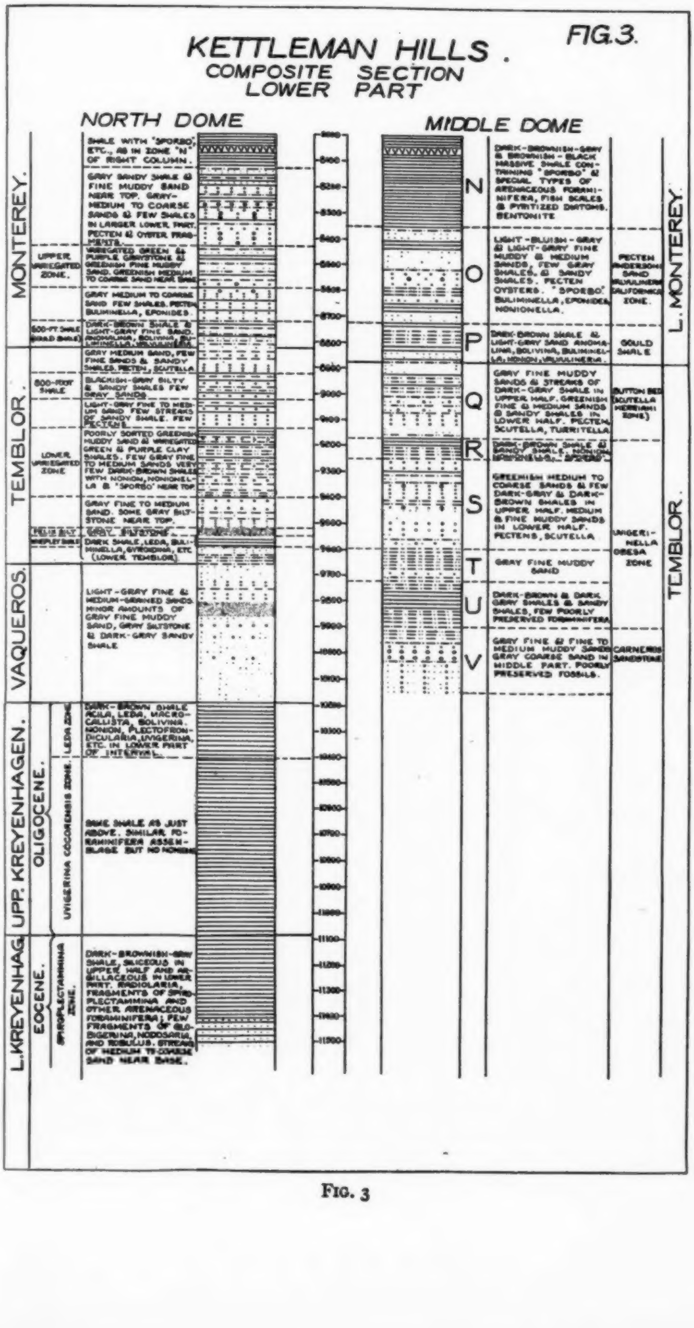
FIG. 3.
KETTLEMAN HILLS.
COMPOSITE SECTION
LOWER PART
NORTH DOME
MIDDLE DOME
MONTEREY.
TEMBLOR.
VAQUEROS.
UPP. KREYENHAGEN.
L. KREYENHAG.
OLIGOCENE.
EOCENE.
UPPER VARIEGATED ZONE.
800-FOOT SHALE
LOWER VARIEGATED ZONE
LEDA ZONE
UVIGERINA COCOAENSIS ZONE.
SPIROPLECTAMMINA ZONE.
SHALE WITH "SPORBO", ETC., AS IN ZONE "N" OF RIGHT COLUMN.
GRAY SANDY SHALE & FINE MUDDY SAND NEAR TOP. GRAY-MEDIUM TO COARSE SANDS & FEW SHALES IN LARGER LOWER PART. PECTEN & OYSTER FRAGMENTS.
VARIEGATED GREEN & PURPLE CLAYSTONE & GREENISH FINE MUDDY SAND. GREENISH MEDIUM TO COARSE SAND NEAR BASE.
GRAY MEDIUM TO COARSE SAND FEW SHALES. PECTEN, BULIMINELLA, EPONIDES.
DARK-BROWN SHALE & LIGHT-GRAY FINE SAND. ANOMALINA, BOLIVINA, BULIMINELLA, VALVULINERIA.
GRAY MEDIUM SAND, FEW FINE SANDS & SANDY SHALES. PECTEN, SCUTELLA
BLACKISH-GRAY SILTY & SANDY SHALES FEW GRAY SANDS.
LIGHT-GRAY FINE TO MEDIUM SAND FEW STREAKS OF SANDY SHALE. FEW PECTENS.
POORLY SORTED GREENISH MUDDY SAND & VARIEGATED GREEN & PURPLE CLAY SHALES. FEW GRAY FINE TO MEDIUM SANDS VERY FEW DARK-BROWN SHALES WITH NONION, NONIONELLA & "SPORBO" NEAR TOP.
GRAY FINE TO MEDIUM SAND. SOME GRAY SILTSTONE NEAR TOP.
GRAY SILTSTONE
DARK SHALE, LEDA, BULIMINELLA, GYROIDINA, ETC. (LOWER TEMBLOR)
LIGHT-GRAY FINE & MEDIUM-GRAINED SANDS. MINOR AMOUNTS OF GRAY FINE MUDDY SAND, GRAY SILTSTONE & DARK-GRAY SANDY SHALE
DARK-BROWN SHALE ACILA, LEDA, MACROCALLISTA, BOLIVINA, NONION, PLECTOFRONDICULARIA, UVIGERINA, ETC. IN LOWER PART OF INTERVAL.
SAME SHALE AS JUST ABOVE. SIMILAR FORAMINIFERA ASSEMBLAGE BUT NO NONION.
DARK-BROWNISH-GRAY SHALE, SILICEOUS IN UPPER HALF AND ARGILLACEOUS IN LOWER PART. RADIOLARIA, FRAGMENTS OF SPIROPLECTAMMINA AND OTHER ARENACEOUS FORAMINIFERA; FEW FRAGMENTS OF GLOBIGERINA, NODOSARIA, AND ROBULUS. STREAKS OF MEDIUM TO COARSE SAND NEAR BASE.
N
O
P
Q
R
S
T
U
V
DARK-BROWNISH-GRAY & BROWNISH-BLACK MASSIVE SHALE CONTAINING "SPORBO" & SPECIAL TYPES OF ARENACEOUS FORAMINIFERA, FISH SCALES & PYRITIZED DIATOMS. BENTONITE
LIGHT-BLUISH-GRAY & LIGHT-GRAY FINE MUDDY & MEDIUM SANDS, FEW GRAY SHALES & SANDY SHALES. PECTEN OYSTERS. "SPORBO". BULIMINELLA, EPONIDES, NONIONELLA.
DARK-BROWN SHALE & LIGHT-GRAY SAND ANOMALINA, BOLIVINA, BULIMINELLA, NONION, VALVULINERIA.
GRAY FINE MUDDY SANDS & STREAKS OF DARK-GRAY SHALE IN UPPER HALF. GREENISH FINE & MEDIUM SANDS & SANDY SHALES IN LOWER HALF. PECTEN, SCUTELLA, TURRITELLA.
GREENISH MEDIUM TO COARSE SANDS & FEW DARK-GRAY & DARK-BROWN SHALES IN UPPER HALF. MEDIUM & FINE MUDDY SANDS IN LOWER HALF. PECTENS, SCUTELLA
GRAY FINE MUDDY SAND
DARK-BROWN & DARK GRAY SHALES & SANDY SHALES, FEW POORLY PRESERVED FORAMINIFERA
GRAY FINE & FINE TO MEDIUM MUDDY SANDS GRAY COARSE SAND IN MIDDLE PART. POORLY PRESERVED FOSSILS.
PECTEN ANDERSONI SAND VALVULINERIA CALIFORNICA ZONE.
GOULD SHALE
BUTTON BED (SCUTELLA MERRIAMI ZONE)
UVIGERINELLA OBESA ZONE
CARNEROS SANDSTONE
L. MONTEREY.
TEMBLOR.

FIG. 3

furnished a few specimens of *Arca trilineata* Conrad, fragmentary shells of *Mya japonica* Jay, fragments of *Mulinia densata* Conrad, and a fairly abundant microfauna represented by *Elphidium hannai* Cushman & Grant, *Elphidium hughesi* Cushman & Grant, *Elphidium striato-punctatum* (Fichtel & Moll), *Eponides* aff. *ornata* (d'Orbigny), ostracods, and echinoid spines.

Two faunas within the Jacalitos formation (Fig. 2, zone D and upper part of H) were detected in cores from the McGlashan well, and also from General Petroleum's Burbank No. 1 (Sec. 30, T. 23 S., R. 19 E.), and Ohio Oil Company's Smith No. 1 (Sec. 35, T. 24 S., R. 19 E.). The upper fauna includes *Arca trilineata* Conrad, *Mytilus* sp., *Panope generosa* Gould, *Pecten oweni* Arnold, and *Pecten estrellanus* Conrad var. *terminus* Arnold. Associated with these forms are *Buliminella elegantissima* (d'Orbigny), *Elphidium hannai* Cushman & Grant, *Elphidium hughesi* Cushman & Grant, *Elphidium* sp. *Eponides* cf. *repanda* (Fichtel & Moll), *Haplophragmoides* sp., and *Nonionella miocenica* Cushman. The organic content of the upper part of zone H is characterized by *Dosinia jacalitosana* Arnold, *Panope estrellana* Conrad, *Solen* sp., and fragments of echinoderms.

The poorly consolidated and prevailingly fine sands composing zone B are characterized by a large percentage of subangular quartz and feldspar grains. In the upper third of the zone these minerals are accompanied by rather common biotite flakes, and sparse green hornblende and hypersthene. In the lower two-thirds of the zone, particularly its lower third, the heavy mineral assemblage becomes more diverse, including, in addition to biotite and green hornblende, augite, basaltic hornblende, and serpentine. Notable percentages of variously colored cherts, and fragments of feldspar crystals with chlorite intergrowth, also appear in this portion.

Mineralogical composition of zones C, D, E, F, G, and the upper 200 feet of zone H, is in general close to that of the lower third of zone B. It is to be noted, however, that serpentine does not extend below the upper third of zone D; the lower limit of augite and of feldspar with chlorite intergrowth seems to coincide with the base of zone F; basaltic hornblende has not been found below zone G, and biotite becomes scarce below the upper half of zone F. Iron oxides occur at several horizons, being particularly abundant in beds 3,580 and 4,130 feet below the top of the section shown in Figure 2.

The lowest zone of the Kettleman Hills Pliocene, zone I, is only tentatively included in the Jacalitos. It differs microfaunally from the definite Jacalitos, particularly zones D and F, only in the presence of *Bolivina* cf. *brevior* Cushman, a species which, though present in

the upper Miocene, is common in beds yielding *Pecten oweni*, *Cryptomya californica*, and other molluscan species typical of the Pliocene.[6] Its lithology, on the other hand, is very similar to that of underlying upper McLure claystone, which contains several foraminiferal species confined to the upper Miocene. The upper McLure claystone seems to grade downward into siliceous shale of the lower McLure.

Relation to underlying formation.—Although the Jacalitos-upper McLure contact was cored in only a few wells, available material clearly indicates a discontinuity in deposition between the two formations. The interval between the lowest Jacalitos sand and the top of the lower McLure ("brown shale") varies, in different wells, from 40 to 700 feet. Moreover, zone I of the Jacalitos is present only in those studied wells[7] located down-dip from the axis of the Kettleman Hills structure. In wells on or close to the axis, not only zone I, but also the top of the upper McLure claystone is missing.[8] In other words, the Jacalitos rests on different horizons of the upper McLure, there being more than 500 feet of strata missing in some wells. The relative structural positions suggest that the higher a well is, the more upper McLure is missing. This is not everywhere obvious, however, because of gaps in coring.

Correlation with Pliocene south of Kettleman Hills.—In the Lost Hills, North Belridge, and Belridge fields, the Pliocene is composed of very fine-grained diatomaceous silts, and siltstones yielding abundant diatoms, alternating with minor amounts of fine sand, sandy clay, and ashy silt (Fig. 5). The microfauna indicates that these are facies of the lower Jacalitos, including zone I. In all three fields the Jacalitos is unconformably overlain by Tulare sands and gravels, the Etchegoin and the San Joaquin clay being apparently absent. At Belridge and North Belridge no indication of disconformity between the Jacalitos and the underlying McLure was observed. At Lost Hills the comparative thinness of the upper McLure implies disconformity. This may be due, however, to inaccurate logging of the top of the lower McLure.

In the Chico Martinez Creek surface section the Jacalitos may be represented by the upper, earthy diatomite. This is suggested by a

[6] In Shell well, Williams No. 1, near the center of San Joaquin Valley, between 7,615 and 9,420 feet. Also in lowest exposed Pliocene at Little Muddy Creek, at the southern edge of the valley.

[7] Kettleman North Dome Association No. 36-30J, Bolsa Chica Oil Ferguson No. 1, Petroleum Securities Robinson No. 1, Standard Oil No. 25-23Q, and Universal Consolidated Bunting No. 1.

[8] Standard Oil No. 2-61-11P and 58-17Q; Superior Oil Huffman No. 1; Shell Oil Dixon No. 1; Ohio Oil Smith No. 1; Kettleman North Dome Association No. 47-2P and 61-20Q.

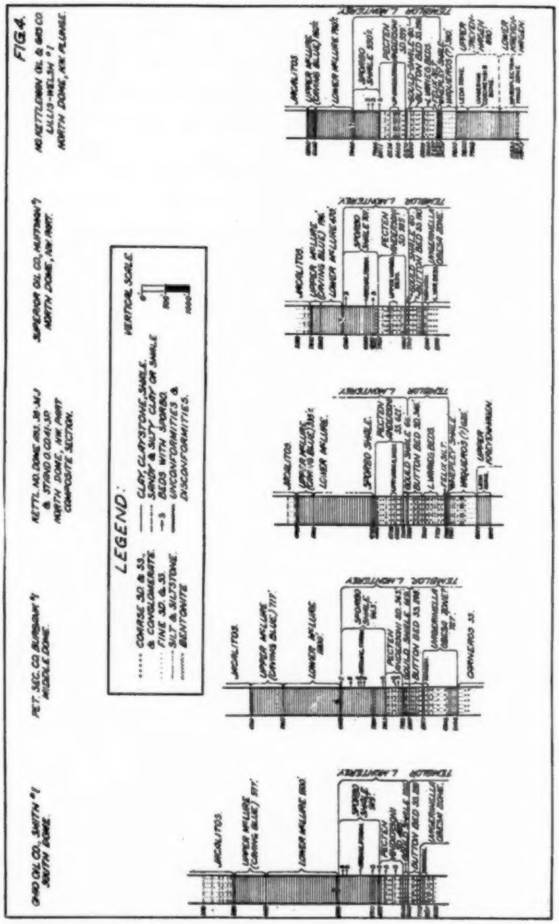

FIG. 4

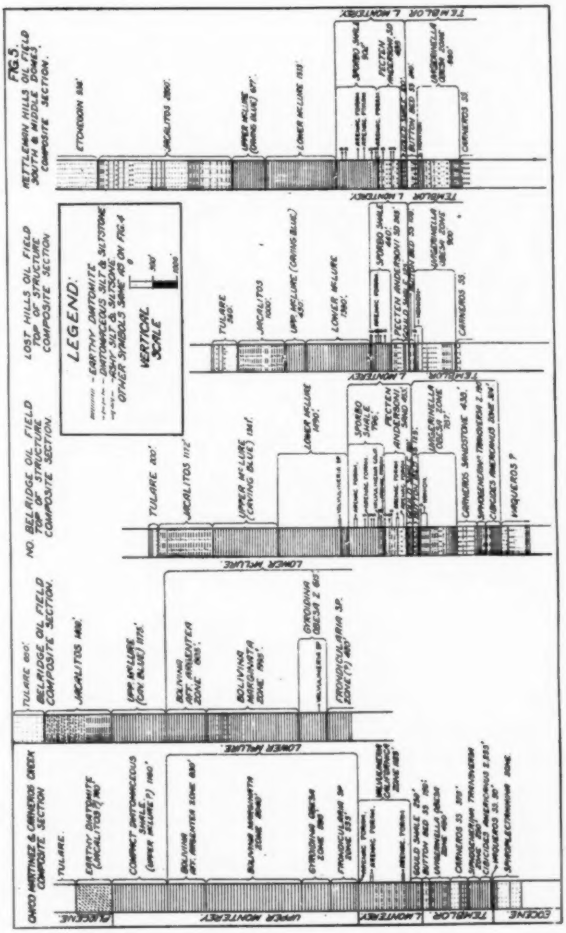

FIG. 5

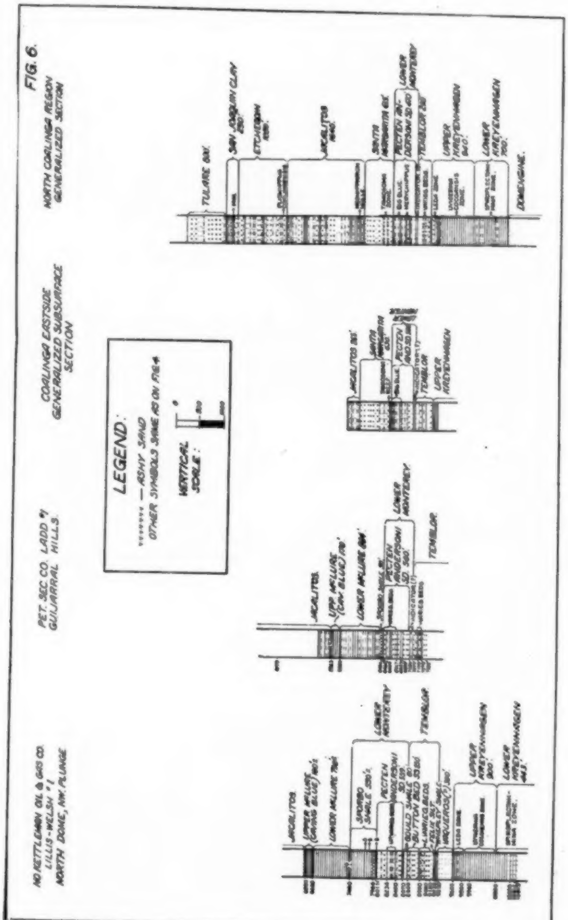
FIG. 6.
NORTH COALINGA REGION GENERALIZED SECTION
COALINGA EASTSIDE GENERALIZED SUBSURFACE SECTION
PET. SEC. CO. LADD #1 GUIJARRAL HILLS
NO. KETTLEMAN OIL & GAS CO. LILLIS-WELSH #1 NORTH DOME, NW. PLUNGE
LEGEND:
—ASHY SAND
OTHER SYMBOLS SAME AS ON FIG. 4
VERTICAL SCALE:

FIG. 6

stratigraphic position of the diatomite similar to that of the diatomaceous silts at Belridge and North Belridge.

Correlation with Pliocene of North Coalinga region.—Correlation of the Pliocene north with that south of Coalinga has been discussed by Nomland.[9] His lithology, faunal zones, and formational divisions are incorporated in Figure 6. Although Nomland found the Jacalitos to contain no fossils excepting vertebrates and plant remains, his correlations seem reliable. Of significance is the abundance of plant remains in the basal Jacalitos reported by Nomland, which feature is also characteristic of the basal Jacalitos at Kettleman Hills and Kreyenhagen Hills. Then, too, samples from North Coalinga show the presence of serpentine there at the same horizons of the Pliocene as at Kettleman Hills. Petroleum Securities well Ladd No. 1 at Guijarral Hills, between the two districts, has furnished cores showing the Jacalitos there to rest on the lowest horizon of the upper McLure, zone I and the highest beds of the upper McLure being missing. This relation is also present at the Jacalitos dome.

Correlation with Pliocene of Kreyenhagen Hills.—Correlation of the Pliocene in wells at Kettleman Hills with the Etchegoin and Jacalitos formations in the Kreyenhagen Hills, as these formations were described by Arnold and Anderson,[10] is given in Figure 7. Comparison of the various sections indicates (1) that the Pliocene of Kreyenhagen Hills is somewhat coarser than at Kettleman Hills; (2) that zone I of Kettleman Hills is missing in the section penetrated by a well at the southeast end of Reef Ridge, and in the surface section at Canoas Creek, showing discontinuity of deposition between the Jacalitos and the upper McLure; and (3) that in Ohio Oil Company's Brix-Welsh No. 1 near Coalinga, not only the basal Jacalitos but also the upper and lower McLure shale are missing, the Jacalitos there resting directly on the "sporbo" shale. Correlation of fossiliferous beds in the Kettleman Hills section with typical sections by Arnold and Anderson[11] for the Kreyenhagen Hills is given in Table II.

MIOCENE

Classification.—Studies of the Monterey at its type locality,[12] and of other Miocene surface sections,[13] indicate, first, that the upper

[9] J. O. Nomland, "Relation of the Invertebrate to the Vertebrate Faunal Zones of the Jacalitos and Etchegoin Formations in the North Coalinga Region, California," *California Univ. Pub. Dept. Geol.*, Vol. 9, No. 6 (1916).

[10] *Op. cit.*, pp. 98–106.

[11] *Op. cit.*, pp. 101, 102, and 119.

[12] G. D. Hanna, "The Monterey Shale at its Type Locality with a Summary of its Fauna and Flora," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 10 (1928), pp. 968–83.

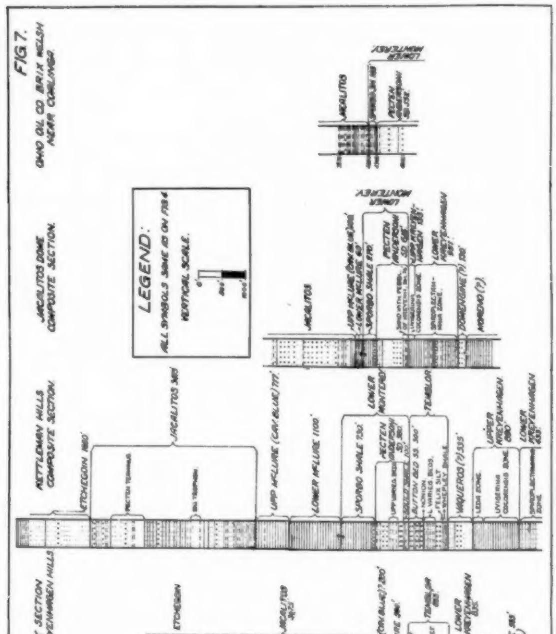

FIG. 7

TABLE II

Kettleman Hills	*Kreyenhagen Hills*	
Subsurface	*Zapato Creek, Surface*	*Canoas Creek, Surface*
Interval between zone with *Arca trilineata* and zone with *Pecten oweni* and *Pecten estrellanus* var. *terminus*	Interval between supposed upper *Mulinia* zone and supposed zone of *Pecten estrellanus*	Interval between upper *Mulinia* zone and bed with *Pecten estrellanus*
1,850 feet	1,750 feet	1,550 feet
Interval between top of zone with *Pecten oweni* and *P. estrellanus* var. *terminus*, and zone with *Panope estrellana* and *Dosinia*	Interval between supposed top of *Pecten estrellanus* zone and Big *Trophon* zone	Interval between top of *Pecten estrellanus* zone and Big *Trophon* zone.
1,700 feet	1,625 feet	1,750 feet
Interval between zone with *Arca trilineata* and zone rich in petrified wood	Interval between supposed upper *Mulinia* zone and beds "full of large fragments of petrified wood"	Interval between upper *Mulinia* zone and base of Big *Trophon* bed
3,750 feet	3,385 feet	3,300 feet

2,830 feet of the type Monterey is upper Miocene, including the highest known Miocene in California; second, that the lower 330 feet of the type section belongs to the *Valvulineria californica* zone, one of the most widespread microfaunal zones in the California Miocene; and, third, that intermediate foraminiferal zones present in other sections[14] are apparently absent at the type Monterey and in the section at Reliz Canyon.

Whether the zones missing in the two sections mentioned represent a separate formation, belong with the upper 2,830 feet of the type Monterey, or belong with the *Valvulineria californica* zone, is unknown. At any rate, their absence at the type Monterey shows a depositional break in the Miocene record. This break may be the Santa Margarita-Monterey unconformity, which Eaton[15] believes is present in strandward territory.

G. D. Hanna and C. C. Church, "Foraminifera from the Type Monterey," a paper presented before the Pacific Section, Society of Economic Paleontologists and Mineralogists (November, 1929).

E. Wayne Galliher, "Stratigraphic Position of the Monterey Formation," *Micropaleontology Bull.*, Vol. 2, No. 4 (1931), pp. 71–74.

[13] Papers presented during the period 1929–1933 before the Pacific Section, Society of Economic Paleontologists and Mineralogists by D. D. Hughes (Modelo Formation in Modelo Canyon); W. D. Rankin (Modelo Formation exposed in Topanga Canyon); P. P. Goudkoff and D. D. Hughes (Chico Martinez Section); W. D. Rankin (Monterey Shale in Reliz Canyon); A. R. May and J. D. Gilboe (Type Temblor Section); and Boris Laiming (Some Aspects of Correlation in the California Miocene).

[14] The *Baggina californica* zone, occurring in the Santa Barbara coastal region, directly above the *Valvulineria californica* zone, and in Topanga Canyon just above the unconformity between the Modelo and Topanga formations, and the *Gyroidina obesa* and *Frondicularia* zones, which overiie the *Valvulineria californica* zone in the Chico Martinez Creek section.

[15] J. E. Eaton, "Standards in Correlation," *Bull. Amer. Assoc. Petrol. Geol.* Vol. 15 (1931), p. 382.

In exposed sections at the Gould Hills, the *Valvulineria californica* zone attains thicknesses as great as 1,100 feet. It is separated from the top of the Temblor formation as originally defined by F. M. Anderson[16] by what Cunningham and Barbat have called the Gould shale.[17]

Analysis of the list of foraminiferal species at Gould Hills within the *Valvulineria californica* zone, the Gould shale, and the Temblor formation as defined by F. M. Anderson (excluding forms which range throughout the Miocene) shows that of 23 species recorded from the Gould shale, 10 are common in the *Valvulineria californica* zone, 6 are confined to the Gould shale of the Gould Hills area but appear with the *Valvulinera californica* assemblage in some other surface section, and only 7 extend downward from the Gould shale into the Temblor. The last-mentioned species have been found in the lower half, only, of the Gould shale at Chico Martinez Creek.

Study of the Miocene at Reliz Canyon, the Santa Maria District, the Santa Barbara coastal region, along the east side of San Joaquin Valley, and on the McDonald anticline, indicates that the microfaunal relationship between the *Valvulineria californica* zone, Gould shale, and Temblor remains the same. That is, species found in the Gould shale at the Gould Hills[18] are elsewhere found superimposed on species which characterize the upper part of the type Temblor.[19]

Cunningham and Barbat[20] are inclined to regard the Gould shale as a member of the Temblor. In their opinion, the upper limit of the Temblor should be raised from the top of the "Button bed," where it was originally placed by F. M. Anderson, to the base of the *Valvulineria californica* zone. The reporting of Temblor mollusks in the *Valvulineria californica* zone[21] might be considered as suggesting that this zone is of Temblor age. Whether a redefinition of the type Temblor is or is not advisable, the microfaunal relation of the *Valvulineria californica* zone, the Gould shale, and the Temblor of F. M. Anderson

[16] F. M. Anderson, "Stratigraphic Study in the Mount Diablo Range, California," *Proc. California Acad. Sci.*, 3d Ser., Vol. 2, No. 2, pp. 156–247.

[17] G. F. Cunningham and W. F. Barbat, "Age of Producing Horizon at Kettleman Hills, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 4 (April, 1932), pp. 417–21.

[18] *Anomalina ammonoides* Reuss; *Bolivina advena* var. *striatella* Cushman; certain species of *Cassidulina*, *Eponides*, and *Lenticulina; Marginulina beali* (Cushman); *Pullenia miocenica* var. *rotunda* (M.S.); *Pulvinulinella subperuviana* Cushman; *Valvulineria californica* var. *appressa* Cushman; *Valvulineria obesa* Cushman, and *Valvulineria miocenica* Cushman.

[19] *Cassidulina margareta* Karrer; *Cibicides floridanus* (Cushman); *Dentalina quadrulata* Cushman & Laiming; *Uvigerinella obesa* Cushman; et cetera.

[20] *Op. cit.*

[21] R. D. Reed, *Geology of California* (Amer. Assoc. Petrol. Geol., 1933), p. 219.

gives, in the opinion of the writer, definite proof that the Gould shale is microfaunally much closer to the *Valvulineria californica* zone than to the Temblor, and that the microfaunal break between the Gould shale and the *Valvulineria californica* zone is insignificant compared with that between the Gould shale and the Temblor.

It is apparent that the *Valvulineria californica* zone and the Gould shale constitute a formation distinct from the Temblor, and are separated by a break in deposition from the larger, upper portion of the type Monterey. Should we retain the name Monterey (as we must because this was the first name introduced into California stratigraphy), it is to be applied to the late upper Miocene of California, and all other names proposed for the formations of this same age (as the members of the "San Pablo group") must be abolished.

For the early upper Miocene, embracing the *Valvulineria californica* zone and Gould shale, a new name might be chosen.[22] However, since the present paper deals with a local problem, the writer does not feel it proper to formally suggest new names for the standard column of California. Therefore, though realizing that two series separated by a break in deposition should not be combined in one formation, he will tentatively designate the *Valvulineria californica* zone and the Gould shale as lower Monterey, and beds equivalent to the upper portion of the type Monterey as upper Monterey.

MCLURE SHALE (UPPER MONTEREY), LATE UPPER MIOCENE

The part of the Kettleman Hills section between the base of the Jacalitos and the top of the so-called "Temblor" sand is locally divided by some field geologists into the "caving blue shale" or Reef Ridge formation, and the "brown" or McLure shale. These two divisions are supposed to be disconformable with one another.[23]

In the present paper the term McLure shale is applied to a lower portion of the "caving blue" and an upper portion of the "brown shale," these being described as the upper and lower McLure, respectively. The upper portion of the "caving blue," as previously mentioned, the writer includes in the Jacalitos. A lower portion of the "brown shale," for reasons to be presented, is referred to the lower Monterey, along with the *Pecten andersoni* sand and the Gould shale.

Upper McLure.—This is compact, massive claystone and siltstone with a prevailingly conchoidal fracture. The color ranges from dark gray with a bluish tint to blackish gray. With the exception of a minor amount of fine sand, the upper McLure retains the same

[22] The best, in the writer's opinion, would be "Reliz formation," after Reliz Canyon, where the beds in question are well exposed and have a thickness of 1,130 feet.

[23] Gester and Galloway, *op. cit.*, p. 1177.

lithological character throughout a thickness of 700 or more feet. However, no well at Kettleman Hills has as yet furnished a continuous set of cores from top to bottom of the upper McLure.

The upper McLure carries rather abundant calcareous foraminifers. The most characteristic are *Bolivina* cf. *seminuda* Cushman; *Bulimina ovata* d'Orbigny; *Globobulimina* sp. (usually much flattened); *Nonionella* sp.; *Virgulina californiensis* Cushman, and *Virgulina* sp. Less frequent are *Buliminella curta* Cushman; *Cassidulina* sp.; *Globigerina bulloides* d'Orbigny; *Globigerina* aff. *triloba* Reuss; *Pulvinulinella* sp.; *Quinqueloculina* sp., and *Uvigerina* sp. Associated with the foraminifers are pyritized diatoms, ostracods, and fish remains.

Cores furnished by three wells[24] from the basal portion of the upper McLure show that this portion (zone K, Fig. 2) contains thin, regular streaks of dark brown shale, well indurated, and rich in pyritized diatoms. The number and thickness of these streaks increases with depth until the top of lower McLure is reached (a solid body of dark, brownish shale characterized by platy texture, zone L, Fig. 2). The basal upper McLure claystone carrying the streaks of brown shale differs microfaunally from the main claystone body above it only in having fewer calcareous foraminifers, more fish remains and pyritized diatoms, and in the appearance of arenaceous foraminifers. The forms of these latter found in the isolated streaks and in the solid body of platy shale are the same.

Lower McLure.—Because of gaps in coring, only a very general description of this division is possible. The thickness of platy shales seems to be not more than 180 feet. Cores below these platy shales show hard, massive, dark brown shale (zone M, Fig. 2) containing sparse pyritic casts of diatoms, radiolarian tests, sponge spicules, more abundant fish remains, and shapeless forms of arenaceous foraminifers. In a few cores, specimens of *Haplophragmoides* and *Cyclammina* were found. The thickness of the massive shale seems to be the least, about 500 feet, in wells near the top of the structure, and increases, up to 1,600 feet, on the flanks and northwest and southeast along the plunges from the apex of the North dome.

Relation of upper to lower McLure.—Aspects of the basal part of the upper McLure claystone suggest that the contact between it and underlying platy shale is gradational. This is substantiated by indirect evidence. Cores from several wells[25] below the depth at which

[24] General Petroleum Ochsner No. 26-2, Petroleum Securities Burbank No. 1, and Ohio Oil Smith No. 1.

[25] Superior Oil Company Huffman No. 1; Petroleum Securities Felix No. 1; Standard Oil No. 2-61-11P.

the top of the "brown shale" was logged have been found to be identical in lithology and microörganic content with the upper McLure claystone. Also, it seems significant that all cores from the top of the "brown shale" show platy shale, and not massive shale such as occurs farther down in the section. The same relations exist in wells at Belridge and North Belridge, and in the Chico Martinez surface section. These are the reasons for the belief of the writer that the lower part of the "caving blue" and the upper part of the "brown shale" form a sedimentary unit. They correspond, probably, to the upper and middle divisions recognized by Henny[26] in the McLure shale of the type locality and along Reef Ridge. In support of such a correlation, samples of silty shale exposed on Reef Ridge at Garza Creek directly *above* hard siliceous shale contain impressions of foraminifers the generic assemblage of which is similar to that of the lower part of the "caving blue shale" at Kettleman Hills.[27] Samples of hard siliceous shale at the type locality of the McLure shale, in Big Tar Canyon, and at Garza Creek, have furnished a *Cyclammina* similar to that in the upper part of the Kettleman Hills "brown shale."

The view that the "caving blue" is depositionally gradational into the "brown shale" seems more in accord with observed facts than does the theory of disconformable contact between the two divisions. At any rate, the writer's studies have failed to detect any evidence in support of the latter theory. Gester and Galloway[28] refer to an occurrence of carbonaceous sand between the "caving blue" and the "brown shale" in wells at Kettleman Hills. The writer has found such a sand in only two wells (Kettleman North Dome Association's No. 81-34Q and No. 76-34Q) both in Sec. 34, T. 22 S., R. 18 E. It was encountered in the wells several hundred feet *below* the logged top of the "brown shale." Its heavy mineral content is identical with that in the lower Jacalitos, and Jacalitos age is indicated by the foraminiferal content of samples from well No. 76-34Q just above and below the sand. A study of samples from this latter well shows an abnormal sequence, which abnormality is probably due to faulting of a type which complicates the structure of North dome.[29]

[26] Gerard Henny, "McLure Shale of the Coalinga Region, Fresno and King Counties, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), p. 404.

[27] The same microfauna, but well preserved, has been detected in dark shale of the Parkfield area classified by Henny as the McLure shale (Gerard Henny, "Presence of the McLure Shale on the West Side of San Joaquin Valley," *Petrol. World and Oil Age*, August, 1930, pp. 97 and 117).

[28] *Op. cit.*, p. 1177.

[29] Gester and Galloway, *op. cit.*, p. 1187.

LOWER MONTEREY (EARLY UPPER MIOCENE)

The work of the writer leads him to conclude that a lower portion of the "brown shale," an upper portion of the so-called "Temblor" sand, and the "600-foot shale," form one unit of sedimentation. This unit seems correlative with that part of the Chico Martinez surface section lying between the top of the *Valvulineria californica* zone and the top of the "Button bed" horizon. The unit is divisible lithologically into three zones: reading downward, the "sporbo" shale, *Pecten andersoni* sand, and Gould shale.

"Sporbo" shale.- Cores from the "brown shale" directly above the so-called "Temblor" sand are different from those in the upper part of this shale. This difference is expressed lithologically by a more distinctly brown (in places brownish black) color, by a more argillaceous composition, and by the presence of one or two closely spaced seams of bentonite. The more important characteristics revealed by microscopic study are the presence of collophane o˙lites known as "sporbo,"[30] special types of fish scales, diatoms (always pyritized), and species of *Gaudryina* and *Haplophragmoides* different from those in the McLure portion of the "brown shale."

Layers especially rich in "sporbo" show remarkable persistance in their position with reference to the bentonite. This is revealed by comparing such layers in Petroleum Securities' Burbank No. 1 (the best cored well in the field) with those cored in other wells, as shown in Table III.

TABLE III

STRATIGRAPHIC INTERVAL, IN FEET, BETWEEN BENTONITE AND LAYERS RICH IN "SPORBO"

Wells *1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
+630	+648	+633	+600	x	x	x	x	+648
+544	+530	+538	+530	x	x	x	x	x
x	+414	+395	x	x	x	+404	x	x
x	+360	x	x	x	x	+348	x	x
x	+190	x	x	x	+187	+183	x	x
x	+75	x	x	+62	x	x	x	+61
x	(−)23	(−)16		(−)8				

+ indicates intervals above the bentonite; (−) intervals below the bentonite; x lack of cores from the corresponding layers. Wells indicated by numerals are: *1*, Ohio Oil Smith No. 1; *2*, Petroleum Securities Burbank No. 1; *3*, Associated Oil Watson No. 1; *4*, Kettleman North Dome Association No. 76–34Q; *5*, Standard Oil No. 78–7Q; *6*, Shell Dixon No. 1; *7*, Petroleum Securities Felix No. 2; *8*, Kettleman North Dome Association No. 36–30J; *9*, Superior Oil Huffman No. 1. Intervals in wells *4*, *6*, and *7* were corrected for the dip observed in cores.

Fish scales and pyritized diatoms, commonly accompanied by pyritized sponge spicules, are in general confined to the lower part of the "sporbo" shale, being particularly common in layers at certain intervals above and below the bentonite.[31]

[30] E. Wayne Galliher, "Collophane from Miocene Brown Shale of California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 3 (1931), pp. 257–69.

Pecten andersoni sand.—A study of available material and of well logs indicates that the "sporbo" shale is nowhere sharply separated from the underlying sand, but grades into it through a series composed of shale streaked with sand, sandy shale, and sand streaked with shale. Another fact suggesting gradational contact is that streaks of shale in the sand usually contain the same types of collophane oölites, fish scales, and pyritized diatoms which occur above in the solid body of "sporbo" shale. The interval between these streaks in sand and the bentonite ofttimes approximates the interval between the bentonite and the layers with "sporbo," fish scales, and diatoms which are confined to the solid body of "sporbo" shale.[32] Because of the lack of an adequate number of samples it is not possible to check the intervals mentioned except in a few wells, but the instances observed make it apparent that certain horizons with "sporbo" pass laterally from shale in one part of the field to sand in another part.

Lateral gradation of parts of the "sporbo" shale into sand would explain why the interval between the bentonite and the top of the sand ranges between 283 and 162 feet in wells drilled on the South dome, Middle dome, and the southeastern end of the North dome, between 69 and 60 feet in wells near the middle of the North dome, and from 53 to 42 feet near the northwestern end of the North dome. Apparently, the farther northwest a well is located the more "sporbo" shale has graded into sand. Interesting variations exist in the relation between the bentonite and the top of the so-called upper variegated zone. The interval between these two markers varies, in wells near the axis of the North dome, from 373 to 328 feet, showing a rather regular decrease from southeast to northwest. Such decrease is particularly noticeable in wells near the northwestern end of the North dome,[33] where the top of the upper variegated zone is encountered from 309 to 295 feet below the bentonite. As an extreme example of this thinning, in North Kettleman Oil and Gas well Lillis Welsh

[31] 200–217, 123–147, 25–39, 8–15, and 3–4 feet above the bentonite and 17–27, 40–44, and 115–120 feet below the bentonite. As in the case of the layers rich in "sporbo," those carrying fish scales and pyritized diatoms show a persistence in stratigraphic position with respect to the bentonite in such widely separated wells as the Ohio Oil Smith No. 1 (South dome) and Kettleman North Dome Association No. 58-50J (northwestern plunge of North dome).

[32] For example, a layer containing "sporbo" and fish scales, lying 110–119 feet below the bentonite, occurs in solid shale in Ohio Oil Smith No. 1 and Kettleman North Dome Association No. 76-34Q wells, whereas in wells Associated Watson No. 1, Standard Oil No. 78-7Q, and Kettleman North Dome Association No. 36-30J, at the same interval below the bentonite, "sporbo" and fish scales are found in streaks of shale interbedded in sand.

[33] Kettleman North Dome Association No. 36-30J and No. 87-30J, and Standard Oil Company No. 67-19J.

No. 1 (far down the northwestern plunge of the North dome) the interval is 268 feet.

In wells near the southeastern end of the North dome, and also in those on the Middle and South domes, the upper variegated zone has not been logged. Nevertheless, mineralogical study of cores from Kettleman North Dome Association's well No. 76-34Q, and from Petroleum Securities' Burbank No. 1 on the Middle dome, reveals that the *Pecten andersoni* sand in these wells not only has the same variation vertically in mineral content as has the sand in wells on the northwestern half of the North dome, but that a distinct suggestion of the upper variegated zone is observable in layers of sand encountered by well No. 76-34Q at a depth of 8,650 feet (stratigraphically 344 feet below the bentonite), and by the Burbank well at 7,665 feet (385 feet below the bentonite).[34]

The organic content of the *Pecten andersoni* sand is largely characterized by the mollusk *Pecten andersoni* Arnold, ofttimes associated with fragmentary oyster shells. These fossils are scattered throughout the sand, being particularly common in the portion 250 to 350 feet below the bentonite. In a few wells *Turritella ocoyana* Conrad has been reported.

The basal portion of the *Pecten andersoni* sand contains a few closely spaced streaks of bluish gray clay which contain calcareous *Foraminifera*. These latter are represented by *Buliminella curta* Cushman, *Buliminella elegantissima* (d'Orbigny), *Buliminella subfusiformis* Cushman, *Eponides* sp., *Nonion* cf. *incisum* (Cushman), *Nonionella* (poorly preserved tests), and occasionally *Globigerina bulloides* d'Orbigny, *Quiqueloculina* sp., and *Pulvinulinella* sp. The bluish gray foraminiferal clay apparently forms a persistent layer, since it was discovered in every well furnishing cores from this part of the section.

Gould shale.—Geologists working in the field recognize as a good marker a series of dark shales and sandy shales occurring within what they call the "Temblor" sand about 600 feet below its top. This is known as the "600-foot shale."

The "600-foot shale" contains a characteristic foraminiferal fauna, including *Anomalina ammonoides* Reuss, *Bolivina advena* var. *striatella* Cushman, *Buliminella curta* Cushman, *Buliminella elegantissima* (d'Orbigny), *Buliminella subfusiformis* Cushman, *Eponides* sp., *Globigerina bulloides* d'Orbigny, *Nonion costiferum* (Cushman), *Valvu-*

[34] A detailed mineralogical study of the Miocene sands from Kettleman Hills wells and from Reef Ridge outcrops has been made by M. N. Bramlette, of the United States Geological Survey. The results of this study may be published in the near future.

lineria cf. *californica* Cushman, *Valvulineria californica* var. *appressa* Cushman, *Valvulineria miocenica* Cushman, and *Valvulineria ornata* Cushman. In some wells there were also found *Marginulina beali* (Cushman), *Nonion incisum* (Cushman), *Pulvinulinella* aff. *subperuviana* Cushman, *Quinqueloculina* sp., some diatoms, fish remains (similar to those in the lower part of the "sporbo" shale), and a few radiolaria tests. Such an assemblage has been detected in each well from which an adequate set of samples was secured. It was found that, while the shale carrying this fauna occurs at different intervals below the top of the sand, the interval between it and the bentonite varies only within small limits even in such widely separated wells as Petroleum Securities' Burbank No. 1 and Superior Oil Company's Huffman No. 1 (Table IV), giving further evidence that variation in thickness of the sand is not due to unconformity, but to gradation into shale.

TABLE IV

STRATIGRAPHIC INTERVAL, IN FEET, BETWEEN BENTONITE AND TOP OF GOULD SHALE

Wells	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	650	646	660	657	654	652	650	652	614	584

Wells indicated by numerals: *1*, Ohio Oil Smith No. 1; *2*, Petroleum Securities Burbank No. 1; *3*, Standard Oil No. 8–1P (depth of the bentonite, not logged in this well, was tentatively placed 61 feet above the top of the sand, this being an average bentonite-sand interval in four nearby wells); *4*, Shell Dixon No. 1; *5*, Petroleum Securities Felix No. 2; *6*, Kettleman North Dome Association No. 56–30J; *7*, Superior Oil Huffman No. 1; *8*, Kettleman North Dome Association No. 58–20; *9*, Standard Oil No. 67–19J; *10*, North Kettleman Oil and Gas Lillis Welsh No. 1.

Here, also, the smaller intervals occur in wells near the northwestern end of the North dome (wells 9 and 10 in Table IV). This fact, like the decrease of the interval between the bentonite and the upper variegated zone, indicates a moderate thinning of the lower Monterey toward the northwest.

Relation of "sporbo" shale (lower "brown shale") to overlying McLure.—Various geologists working in the Kettleman Hills field are of the opinion that the entire body of "brown shale" is correlative with the typical McLure shale, and that it rests unconformably upon the underlying sand. This assumption has been drawn upon to explain the tremendous variation in thickness of the "brown shale," ranging from 920 feet in some North dome wells, to 2,415 feet in Ohio Oil Company's Smith No. 1 on the South dome.

Attractive as the theory of unconformity between the "brown shale" and the underlying sand may appear at first glance, it seems contradictory to a number of observed facts. If there were unconformity one would expect different horizons of the "brown shale" to be in contact with different horizons of the underlying sand. On the contrary, as has been shown, there is remarkable persistence in the interval between various "sporbo" layers and the bentonite, between

the bentonite and the top of the upper variegated zone, and between the bentonite and the Gould shale. Variation in stratigraphic position of the bentonite with respect to the top of the sand is minor compared with the tremendous variation in thickness of the "brown shale." It should be kept in mind that the bentonite taken as a datum point in these discussions is considered by field geologists to be an excellent marker when correlating wells,[35] and that variation in the interval between this marker and the other horizons has been traced throughout the field by means of closely spaced wells.

Irreconcilably opposed to the theory of unconformity between the "brown shale" and the sand is the gradational contact between the two divisions. Less definite, but strongly suggestive, is the apparent lateral gradation from shale to sand, as shown by the lateral extension of certain "sporbo" layers from one texture to the other.

If the conclusion that there is no break in deposition between the sand and the part of the "brown shale" to which the bentonite is confined be accepted, there seem to be only two possible explanations of the tremendous variation in thickness of the "brown shale" as a whole. These are (1) that there is disconformity somewhere within the shale above the bentonite, or (2) that variation in thickness of the shale is due to extreme variation in deposition within a limited area. Because of the apparently consistent intervals between the bentonite and the layers rich in "sporbo," and also for other reasons to be presented, the writer is inclined to think the most probable explanation to be a disconformity between the upper part of the "brown shale" (McLure shale), and the lower part of the "brown shale" ("sporbo" shale). The latter would thus represent the highest division of a unit which includes the underlying *Pecten andersoni* sand and the Gould shale.

TEMBLOR AND VAQUEROS (LOWER MIOCENE)

Temblor (*late lower Miocene*).—The most important characteristics of the strata underlying the Gould shale are given on Figure 3. Only a few explanatory remarks need be made.

Shells and fragments of a *Scutella* have been found by the writer in beds below, and only below, the Gould shale.[36] In all wells furnishing cores 344–447 feet below the top of the Gould shale, there have been found, at this horizon, rather abundant "sporbo" associated

[35] Gester and Galloway, *op. cit.*, p. 1177.

[36] In wells Ohio Oil Smith No. 1 (7,561–7,612 feet); Petroleum Securities Burbank No. 1 (8,169 and 8,485–8,493 feet); Standard Oil No. 8-1P (7,025 feet); Kettleman North Dome Association No. 36–30J (8,693–8,714 feet), and Superior Huffman No. 1 (7,965 feet).

with *Foraminifera*. The latter form an assemblage composed of *Nonion incisum* Cushman (very common), *Nonionella* sp. (very common), *Bolivina* sp. (rare), and *Virgulina* sp. (rare). A similar assemblage has been found by the writer in several surface sections, and in wells drilled elsewhere in San Joaquin Valley, in strata immediately below the "Button bed" sandstone, and, in part, within this sandstone.

In North dome wells the *Nonion-Nonionella* fauna seems to be confined to streaks of dark brown shale interbedded with greenish and purple beds which form the top of the so-called second or lower variegated zone. The heavy mineral content of this zone is characterized by the presence of epidote, hornblende, and augite, which minerals are completely lacking in sands classified by the writer as the "Button bed" sandstone (Fig. 4).

In wells drilled on the Middle and South domes the lower variegated zone has not been recognized megascopically. It is interesting to note, however, that in Petroleum Securities' Burbank No. 1 a sudden appearance of epidote (40 per cent of the heavy residue) has been recorded a short distance above the shale carrying the *Nonion-Nonionella* fauna, and that the first hornblende has been found in cores just below the *Nonion-Nonionella* fauna.

Analyzing the various data on the depth at which the top of the lower variegated zone is reached, we see, again, that the interval between this marker and the bentonite within the "sporbo" shale shows little variation, and decreases toward the northwest. Table V gives an example of this last evidence of the variation.

TABLE V

STRATIGRAPHIC INTERVAL, IN FEET, BETWEEN BENTONITE AND TOP OF LOWER VARIEGATED ZONE

Petroleum Securities Burbank No. 1	*Standard Oil No. 2-61-11P*	*Standard Oil No. 41-3P*	*Superior Oil Huffman No. 1*	*Standard Oil No. 34-29J*	*North Kettleman O. & G. Lillis Welsh No. 1*
1,093	1,086	1,076	1,053	1,048	964

The lowest Temblor marker at present recognized in North dome wells by field geologists is locally known as the Whepley shale. Examination of samples from this shale shows it to contain a small amount of glauconitic concretions and fairly abundant *Foraminifera*. The latter are *Bolivina marginata* Cushman; *Bolivina* sp.; *Buliminella curta* Cushman (the most abundant species); *Cancris sagra* (d'Orbigny); *Cibicides floridanus* (Cushman); *Cyclammina incisa* (Stache); *Dentalina quadrulata* Cushman & Laiming; *Dentalina* sp.; *Gaudryina triangularis* Cushman; *Gyroidina soldanii* d'Orbigny; *Globobulimina* (crushed specimens); *Plectofrondicularia* sp.; *Robulus nikobarensis*

(Schwager); *Robulus simplex* (d'Orbigny); and *Robulus* sp. This assemblage indicates that the Whepley shale is a correlative of the basal Temblor exposed at Chico Martinez Creek, the fauna occurring 1,190 feet and 1,250 feet stratigraphically below the top of the "Button bed" sandstone at that locality.

In Petroleum Securities' Burbank No. 1 on the Middle dome, strata resembling the Whepley shale were encountered (zone U, Fig. 3). The foraminiferal assemblage, however, which is poorly preserved, appears to be that at the base of the *Uvigerinella obesa* zone rather than that of the basal Temblor. The Whepley shale, in the opinion of the writer, has not been reached in the Burbank well, which means that the lower portion of the Temblor formation at Kettleman Hills thins more rapidly toward the northwest than does the upper portion. Other evidence of this is given later.

Vaqueros (early lower Miocene).—A body of sand penetrated by Kettleman North Dome Association's well 38-34J (7,911–8,547 feet) and by the North Kettleman Oil and Gas well Lillis Welsh No. 1 (9,250–9,600 feet), between the base of the Whepley shale and the top of the upper Kreyenhagen, is provisionally classified by the writer as Vaqueros. Since no organic remains have been found in this sand, the identification is of course only tentative. It is based on the fact that the age of the Whepley shale overlying this sand body is basal Temblor, whereas the shale underlying it represents the very top of the upper Kreyenhagen.

Heavy mineral analysis of the supposed Vaqueros sand reveals a large percentage of pyrite concretions. Of other minerals, only small amounts of biotite, titanite, and zircon have been found.

Comparison of the thickness of the Vaqueros (?) sand in well No. 38-34J with its thickness in the Lillis Welsh well indicates that this formation, too, thins considerably toward the northwest, or from 636 to 350 feet.

CORRELATION WITH MIOCENE SOUTH OF KETTLEMAN HILLS

The Kettleman Hills Miocene is best correlated by comparing it with the Miocene surface section at Chico Martinez Creek in the Gould Hills (Fig. 5). The part of the Gould Hills section above the "Button bed" is compiled from the description by Goudkoff and Hughes. The lower portion summarizes a study by Goudkoff, Hughes, and Laiming at Chico Martinez Creek, and by May and Gilboe at Carneros Creek.

At first glance, the two columns are not readily correlated, but by progressing by stages from Kettleman Hills through the Lost Hills, North Belridge, and Belridge fields, it is possible to recognize

in each of these fields distinct markers which can be detected in the Chico Martinez Creek section. For instance, the upper member of the McLure shale, and its gradational contact with the lower McLure, is easily traced from Kettleman Hills through Lost Hills and North Belridge over to the Belridge section. Then too, the "sporbo" shale and the *Pecten andersoni* sand of the Kettleman Hills section have well-defined equivalents in the Lost Hills and North Belridge wells. In the last two sections a Gould shale microfauna which is present contains foraminiferal species similar to those in Kettleman Hills wells, and also to those in the Gould shale at Chico Martinez Creek. Another tie between the North Belridge and Belridge fields is the horizon indicated on Figure 5 by the words "*Valvulineria* sp.," which contains a foraminiferal assemblage to be discussed later. Finally, the entire Belridge section below the base of upper McLure is duplicated in the Chico Martinez section between the top of the so-called *Bolivina* aff. *argentea* zone and the base of the *Frondicularia* zone. Under the guidance of these markers, correlation of the Chico Martinez Creek and Kettleman Hills sections can be made without difficulty, and may be summarized as follows:

The upper McLure is apparently represented in the Chico Martinez section by compact diatomaceous shale composing the part of the section between the Jacalitos (?) diatomite and the top of the *Bolivina* aff. *argentea* zone. This is suggested by a stratigraphic position of the compact diatomaceous shale similar to that of the upper McLure of the Belridge field, which latter is well characterized microfaunally.

The lower McLure of the Kettleman Hills section is correlated with the shale embracing the *Bolivina* aff. *argentea* and *Bolivina marginata* zones at Chico Martinez Creek. The lack of calcareous *Foraminifera* in the lower McLure at Kettleman Hills presumably results from a gradual disappearance of these microfossils between the Belridge and Lost Hills field, explainable by a change in ecologic conditions.

The horizon at North Belridge containing pyritized tests of certain species of *Bolivina, Buliminella, Cibicides, Uvigerina,* and *Valvulineria* is duplicated by a layer (indicated on Fig. 5 by the words "*Valvulineria* sp.") penetrated by General Petroleum's Berry No. 1 at Belridge, and is correlative with a lower portion of the *Gyroidina obesa* zone at Chico Martinez Creek. Comparison of the Belridge, North Belridge, and Lost Hills sections suggests that the *Gyroidina obesa* and *Frondicularia* zones wedge out toward the north. The two zones form the basal portion of the McLure shale, which apparently overlaps the "sporbo" shale. In support of this view is the appearance

of collophane oölites and other features characteristic of the "sporbo" shale in North Belridge wells below the *Gyroidina obesa* zone, which is the horizon carrying pyritized *Foraminifera*. Furthermore, *Foraminifera* characteristic of the zones in question are found in basal beds of the McLure shale on Reef Ridge. On the other hand, one may see (Fig. 5) that the stratigraphic interval between the top of the lower McLure and the horizon with pyritized *Foraminifera* in the Belridge section is 3,280 feet, whereas at North Belridge the interval is 1,365 feet. Since it does not seem reasonable to ascribe all of this enormous variation to thinning of the McLure shale, the question arises whether the *Gyroidina obesa* and *Frondicularia* zones belong with the *Valvulineria californica* zone, or whether they are separated from this, as well as from the McLure shale, by breaks in deposition, and form an independent unit. The material at hand does not permit a definite answer.

The "sporbo" shale, *Pecten andersoni* sand, and Gould shale of the North Belridge section leave no doubt regarding their equivalency to these divisions at Lost Hills and Kettleman Hills. These parts of the North Belridge section, in turn, correlate with the *Valvulineria californica* zone and Gould shale of the Gould Hills region. For instance, the presence of the *Valvulineria californica* fauna in the "sporbo" shale of the Gould Hills and the North Belridge field definitely correlates these two sections, and the characteristic "sporbo" shale continues through the Lost Hills to and beyond the Kettleman Hills. Furthermore, the position of certain arenaceous *Foraminifera* in the Gould Hills section (see Fig. 5) is paralleled by a similar position in the lower Monterey at the North Belridge, Lost Hills, and Kettleman Hills field. Finally, the position of the *Pecten andersoni* sand in North Belridge wells corresponds closely to the position of sandy and silty shales within the *Valvulineria californica* zone at Chico Martinez Creek. In this connection, streaks of sand are found within the *Valvulineria californica* zone on the McDonald anticline as much as 700 feet above the top of the Temblor (reef yielding *Scutella merriami*).

North Belridge is also a connecting link between the Gould Hills and the Kettleman Hills for the correlation of Temblor strata. It contains every Temblor zone recognized at the Gould Hills, and also several markers of the Lost Hills and Kettleman Hills sections. The markers are: (1) the shale with the *Nonion-Nonionella* fauna, an equivalent of which has been found in all wells at Lost Hills, and at Kettleman Hills, furnishing core material from this part of the section; (2) The microfauna near the base of the *Uvigerinella obesa* zone,

which fauna is closely related to one in a well at Lost Hills and to one in Petroleum Securities' Burbank No. 1 on the Middle dome at Kettleman Hills between 8,950 and 9,032 feet; and (3) the basal Temblor (Whepley shale of the Kettleman Hills North dome).

From the columnar sections on Figures 5 and 8 it will be observed that the Temblor thickens between the Gould Hills and North Belridge field from 1,480 feet to 1,864 feet, and then seemingly retains this thickness, at least from its top down to the Carneros sandstone, northward[37] to the Middle dome at Kettleman Hills. Between the Middle and North domes it thins to 835 feet (Figs. 3 and 8).

CORRELATION WITH MIOCENE WEST OF KETTLEMAN HILLS

Study of the Miocene exposed along Reef Ridge, and penetrated in wells near the southeast end of Reef Ridge, at the Jacalitos dome, and near the town of Coalinga, has led to the conclusions given below (consult Figs. 7 and 8).

The thickness of the upper member of the McLure shale in these areas is in general much less than at Kettleman Hills, decreasing progressively towards the northwest from 340 feet in a well at the southeast end of Reef Ridge to 100 feet on the Jacalitos dome, and to nothing in Ohio Oil Company's Brix-Welsh No. 1 near Coalinga.

The lower member of the McLure shale at Reef Ridge differs from this member at Kettleman Hills in several features. First, the McLure shale penetrated by the well at the southeast end of Reef Ridge, and also that exposed along Reef Ridge, contains (especially in the middle and lower portions of the formation), considerable sandy shale and sand. Second, a bentonite cored in the well near Reef Ridge about 575 feet above the unconformable McLure-Temblor contact, occurs in Reef Ridge exposures, close to the contact. The writer believes that this bentonite is not the one at Kettleman Hills within the "sporbo" shale. Third, the McLure shale exposed on Reef Ridge yields assemblages of calcareous *Foraminifera* not found in any well at Kettleman Hills. One of these assemblages was detected by R. M. Kleinpell in a sample from shale exposed near Sulphur Spring Gap about 12 feet above the McLure-Temblor unconformable contact. The *Foraminifera* of this sample are closely related to those of the *Gyroidina obesa* zone at Chico Martinez Creek, and include species of *Valvulineria* present in the pyritized *Foraminifera* at Belridge and North Belridge. Another assemblage, from the well at the southeast end of Reef Ridge a short distance above the McLure-Temblor con-

[37] The thickness of this part is 912 feet at North Belridge, 1,000 at Lost Hills, and 1,025 in Petroleum Securities' Burbank No. 1.

tact, is that of the *Frondicularia* zone of Chico Martinez Creek. The extra assemblages, together with the extra bentonite, suggest that in the Reef Ridge area a portion of the McLure shale is present which is absent at Kettleman Hills.

The lower McLure of Reef Ridge thins northwesterly in much the same manner as does the upper McLure; from 1,460 feet in the well at the southeast end of Reef Ridge to 500 feet on the Jacalitos dome, and then to nothing in the Ohio Oil Company's Brix-Welsh No. 1.

While the "sporbo" shale and *Pecten andersoni* sand are present in wells on the Jacalitos dome and in the Ohio Oil Company's Brix-Welsh No. 1, no "sporbo" have been found in shales exposed along Garza Creek and Canoas Creek, a short distance west, or in those penetrated in the well at the southeast end of Reef Ridge. In the wells on Jacalitos dome, and in the Brix-Welsh well, the "sporbo" shale is 270–168 feet thick, whereas in wells at Kettleman Hills it attains a thickness of more than 900 feet. The thinning is due to an absence of the upper part of the "sporbo" shale. This is further evidence of a break in deposition between this shale and the McLure shale.

Sandstones unconformably underlying the McLure shale along Reef Ridge are not younger than the one at Kettleman Hills herein correlated with the "Button bed" sandstone. This conclusion is based on the following observations. 1. Heavy mineral analyses of sands exposed along Garza Creek show that, downward from a layer less than 250 feet below the McLure overlap, the sands contain epidote, augite, and hornblende, which minerals, as mentioned, form an assemblage characteristic of the so-called lower variegated zone of the undoubted Temblor at Kettleman Hills. 2. The *Nonion-Nonionella* assemblage, occurring at Kettleman Hills near the top of the lower variegated zone (200–400 feet below the base of the Gould shale), has been found in a streak of shale at Big Tar Canyon about 400 feet stratigraphically below the unconformable McLure-Temblor contact. In the well at the southeast end of Reef Ridge the same fauna has been found in shale 190 feet below the McLure-Temblor unconformity.

The mineralogical composition of samples from Garza Creek shows that the epidote-augite-hornblende assemblage extends down to a horizon less than 90 feet above the Temblor-Kreyenhagen unconformity. In wells at Kettleman Hills the base of the epidote-augite-hornblende zone is 200 or more feet above the base of the Temblor. This indicates that, in some localities at least along Reef Ridge, the basal Temblor is missing. In the well at the southeast end of Reef Ridge, however, both the basal Temblor and strata herein assigned

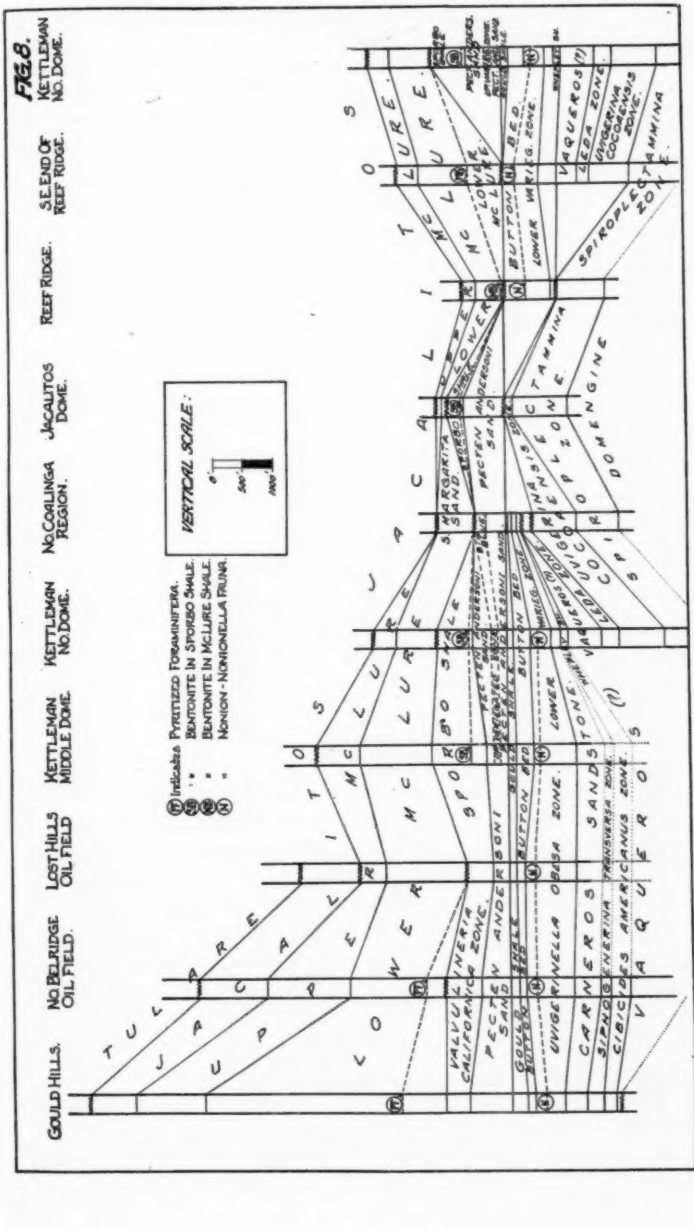
FIG. 8.
GOULD HILLS.
NO. BELRIDGE OIL FIELD.
LOST HILLS OIL FIELD
KETTLEMAN MIDDLE DOME.
KETTLEMAN NO. DOME.
NO. COALINGA REGION.
JACALITOS DOME.
REEF RIDGE.
S.E. END OF REEF RIDGE.
KETTLEMAN NO. DOME.
(P) indicates PYRITIZED FORAMINIFERA.
(S) " BENTONITE IN SPORBO SHALE.
(M) " BENTONITE IN MC LURE SHALE.
(N) " NONION - NONIONELLA FAUNA.
VERTICAL SCALE:
0'
500'
1000'
TULARE
JACALITOS
UPPER
LOWER
MC LURE
SPORBO SHALE
VALVULINERIA CALIFORNICA ZONE.
PECTEN ANDERSONI SAND
GOULD SHALE
BUTTON BED
UVIGERINELLA OBESA ZONE.
CARNEROS SANDSTONE
SIPHOGENERINA TRANSVERSA ZONE.
CIBICIDES AMERICANUS ZONE.
VAQUEROS
MARGARITA SAND.
LOWER VARIEG. ZONE.
VAQUEROS
LEDA ZONE
UVIGERINA COCOAENSIS ZONE.
SPIROPLECTAMMINA ZONE.
DOMENGINE

FIG. 8

to the Vaqueros are apparently present. This is suggested by the thickness of sand penetrated between the McLure-Temblor unconformity and the top of the Kreyenhagen shale, a thickness approximating that at Kettleman Hills between the top of the "Button bed" sandstone and the top of the Kreyenhagen shale. The uppermost layer of the Kreyenhagen shale is similar in both well sections.

CORRELATION WITH MIOCENE OF NORTH COALINGA REGION

In the Petroleum Securities' Ladd No. 1 at Guijarral Hills (Fig. 6) only a small portion of the well section, that between depths of 5,343 and 5,520 feet, is assigned to the upper McLure shale. The micro-organic contact of this portion suggests that it is equivalent to the lowest beds of the upper McLure penetrated by the Petroleum Securities' Burbank No. 1 on the Kettleman Hills Middle dome. Thus, in the Ladd well, upper strata appear to be cut out by an overlap of the Jacalitos.

The part of the Ladd well section assigned to the lower McLure yields *Foraminifera* characteristic of this division at Kettleman Hills, but differs from the latter section in the presence of many layers of sandy shale. The sandy character of the McLure shale at Guijarral Hills forms an intermediate link in the gradation of the formation from a compact shaly facies at Kettleman Hills to sands in the North Coalinga region commonly called Santa Margarita.

The "sporbo" shale is very thin in the Ladd well, where it occurs at depths between 6,433 feet and 6,450 feet. It is entirely lacking in Coalinga Eastside wells and northward.

The horizon of the *Pecten andersoni* sand can be traced from Kettleman Hills North dome through the Guijarral Hills to north of Coalinga. The "Big Blue" beds north of Coalinga are lithological equivalents of the upper variegated zone at Kettleman Hills. White sands yielding *Merychippus*, and greenish gray, gray, and brown sands in the North Coalinga region below the *Merychippus* zone, represent the lower part of the *Pecten andersoni* sand of Kettleman Hills.

Shale penetrated in the Ladd well between 7,024 and 7,079 feet is tentatively correlated with the Gould shale, the so-called "black shale" of the Coalinga Eastside field, and the "indicator" bed of the North Coalinga region. Unfortunately, no *Foraminifera* have been found in exposures of the "indicator" bed along the foothills between Oil City Camp and Cantua Creek. The correlation mentioned is based on lithological similarity of the beds above and below the "indicator" bed to those overlying and underlying the Gould shale at Kettleman Hills North dome. Resemblance of the upper variegated zone at the

North dome to the "Big Blue," and of the lower variegated zone to similar beds of the North Coalinga region below the "indicator" bed, is particularly striking. The decreasing interval between the markers emphasizes the thinning of the lower Monterey and the Temblor toward the northwest. The interval from the base of the upper variegated zone down to the top of the lower variegated zone in the North dome wells is 555 feet, in the Ladd well No. 1 is 495 feet, and from the base of the "Big Blue" down to the variegated beds below the "indicator" bed in the North Coalinga section is 350 feet.

The unconformity in the North Coalinga region between the Temblor and the Kreyenhagen shale cuts out the basal Temblor and all of the Vaqueros.

AGE OF PRODUCING HORIZON AT KETTLEMAN HILLS

Correlation of the upper 600 feet (*Pecten andersoni* sand) of the producing horizon at Kettleman Hills with the *Valvulineria californica* zone was first made by the writer in July, 1931.[38] A few months later this correlation was criticized by Cunningham and Barbat,[39] who concluded that "the oil horizon of Kettleman Hills consists of the Temblor formation of the type section." The writer has since examined considerable new material, and has become more convinced of the correctness of his original correlation. It is deemed advisable to explain here why he can not agree with his critics.

The keystone of Cunningham and Barbat's arguments is, that the Gould shale, which they define as "a shale member between the base of the *Valvulineria californica* zone and the top of the 'Button bed' sandstone" at the type Temblor, "is Temblor in age." In support of this conclusion, the authors state that (1) "the base of the *Valvulineria californica* zone coincides with the base of the Monterey formation at its type locality"; (2) the Gould shale "contains an assemblage of *Foraminifera* which is distinct from that of the *Valvulineria californica* zone"; (3) "this assemblage [present in the Gould shale] is found elsewhere in the San Joaquin Valley, associated with Temblor molluscan fossils, and is actually repeated within shale streaks in the 'Button bed' sandstone, in well sections,"[40] and (4) "*Pecten andersoni* has not been found in any part of the Monterey formation in the San Joaquin Valley." They also refer to "the similarity of the Kettleman Hills well sections" to outcrops of the Temblor at Reef Ridge, and suggest "that the Monterey formation has its maximum

[38] Paul P. Goudkoff, "Age of Producing Horizon at Kettleman Hills, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), pp. 839–42.

[39] *Op. cit.*

[40] *Op. cit.*, p. 420.

development in the San Joaquin Valley in the Chico-Martinez and Carneros Creek areas and becomes thinner north and northwest by progressive overlap onto unnamed shale with Temblor affinities and older strata."[41]

Comment by the writer on these statements is as follows. 1. The lowest bed of the type Monterey cannot be considered as necessarily the extreme base of the Monterey formation, or even as the base of the *Valvulineria californica* zone, because this bed rests unconformably on Santa Lucia quartz diorite, indicating that the extreme base of the formation is not represented at its type. 2. The foraminiferal assemblage of the Gould shale, as pointed out in the present paper, is much more closely related to that of the *Valvulineria californica* zone than to that of the type Temblor. 3–4. The occurrence of Temblor mollusks with a Gould shale foraminiferal assemblage is not conclusive evidence of the Temblor age of the Gould shale, because *Turritella ocoyana*, *Pecten andersoni*, and other mollusks occurring in the Temblor have been reported at certain localities to lie side by side with the *Valvulineria californica* microfauna,[42] which latter characterizes the lower part of the type Monterey and occurs above the type Temblor as originally defined. Thus, if a preference for determination of age be granted to molluscan fossils, one should include in the Temblor formation not only the Gould shale, but also the *Valvulineria californica* zone. The latter, however, Cunningham and Barbat admit is Monterey. The reported presence of a Gould shale foraminiferal assemblage in shale streaks within the "Button bed" sandstone has not been substantiated by the writer's studies. Nor could the supposed occurrence in wells be checked, because it was not stated in what wells the streaks were observed.

As previously pointed out, the epidote-augite-hornblende mineral assemblage is present in the Temblor outcrop along Garza Creek not more than 250 feet below the McLure-Temblor unconformity, whereas at Kettleman Hills this assemblage begins near the top of the lower variegated zone, about 1,000 feet below the top of the *Pecten andersoni* sand. Also, the *Nonion-Nonionella* fauna is present in the Temblor outcrop at Big Tar Canyon about 400 feet below the McLure-Temblor unconformity, an interval which is closely paralleled by the interval between the base of the Gould shale and the *Nonion-Nonionella* layer at Kettleman Hills. Mineralogical studies of the Reef Ridge Temblor by Bramlette[43] lead him to believe that the upper portion

[41] *Op. cit.*, p. 421.

[42] R. D. Reed, *op. cit.*, p. 219. Also, information obtained from W. D. Kleinpell.

[43] M. N. Bramlette, personal communication, July, 1933.

of the so-called "Temblor" sand of the Kettleman Hills section may be missing at the Reef Ridge outcrop. In view of these studies, Cunningham and Barbat's reference to "the similarity of the Kettleman Hills well sections" to the Temblor outcrops at Reef Ridge is at least doubtful.

Features of the contact between the "brown shale" and the underlying *Pecten andersoni* sand, as described above, show that the two divisions are conformable. Also, Gester and Galloway[44] mention without criticism "the opinion that the unconformity indicated from regional relations could not reasonably be placed at the top of the sand in all of the wells" at Kettleman Hills. From these features it appears that Cunningham and Barbat's "progressive overlap" of the Monterey shale "onto unnamed shale with Temblor affinities and older strata" remains to be proved.

OLIGOCENE AND UPPER EOCENE

KREYENHAGEN GROUP

The general succession called Kreyenhagen shale includes two formations. The upper formation is known to micropaleontologists as the *Uvigerina cocoaensis* zone. It corresponds to the "upper member of the Kreyenhagen shale proper" as defined by Jenkins,[45] but includes, as its uppermost portion, the so-called *Leda* zone.[46]

In the North Coalinga region, the *Uvigerina cocoaensis* zone or upper Kreyenhagen can be traced for more than 40 miles north of Coalinga, being best exposed along Domengine Creek. It is there composed largely of organic shales, but in the Cantua Creek-Panoche Creek district it includes, in its lower half, some sandstone layers.[47] West of Wagonwheel Mountain the formation is represented by the upper 425 feet of shale unconformably underlying the Temblor, and includes, near its base, the sandstone tentatively correlated by Jenkins[48] with the San Emigdio formation.

[44] *Op. cit.*, p. 1179.

[45] O. P. Jenkins, "Stratigraphic Significance of the Kreyenhagen Shale of California," *Mining in California*, Vol. 27 (1931), p. 147.

[46] The foraminiferal assemblage present in the *Leda* zone at its type locality is, except for two species, identical with that in shales underlying the zone at that locality. This fact, the very limited area within which the zone is developed, and the small thickness of the zone, suggest that the unconformity at the base of the zone is only a minor break in deposition. An excellent collection of *Foraminifera* from the type of the *Leda* zone was kindly loaned the writer by A. R. May.

[47] D. D. Condit, "Age of the Kreyenhagen Shale in Cantua Creek-Panoche Creek District," *Jour. Paleontology*, Vol. 4, No. 3 (1930), pp. 259–62. Jenkins has termed this part of the formation the "intermediate sandstone and shale member" (*op. cit.*, p. 145). The work of the writer shows, however, that *Foraminifera* found in the shales of the "intermediate member" as well as those directly below it form an assemblage identical with the *Uvigerina cocoaensis* zone.

[48] *Op. cit.*, p. 146.

The foraminiferal assemblage of the *Uvigerina cocoaensis* zone has a close affinity with one described from the Bassendorf and the Keasy shales of the Oregon Coast Range,[49] which shales have tentatively been assigned to the lower Oligocene. Other evidence of Oligocene age of the formation is furnished by mollusca present in sandstones of the Cantua Creek-Panoche Creek district,[50] and in the sandstone member of the formation exposed near Wagonwheel Mountain.[51]

The organic content of the lower Kreyenhagen has not as yet been studied in all its details. The best description is that by Hughes and Laiming.[52] They tentatively concluded that it contains two recognizable foraminiferal assemblages, which they have termed the upper and lower stage of the *Spiroplectammina* fauna. One more fauna, showing close affinity with that of the Markley formation figured by Church[53] from Contra Costa County, California, has been noted by them in the Cantua Creek area.

The stratigraphic position of the "Markley" fauna has not been established beyond the fact that it occurs between the *Uvigerina cocoaensis* zone above, and the upper stage of the *Spiroplectammina* fauna below. Church[54] reports the fauna from highly distorted shales thought to be near the base of the Kreyenhagen as exposed in Oil Canyon, north of Coalinga. The writer has detected a similar foraminiferal assemblage in about 200 feet of shale penetrated by the well at the southeast end of Reef Ridge, directly below the *Uvigerina cocoaensis* zone. A few *Foraminifera* in the uppermost 100–150 feet of the Kreyenhagen exposed in Big Tar Canyon, and also in the uppermost 50–60 feet of the formation in Canoas Creek, suggest that these shales may contain equivalents of the "Markley" fauna.

The upper stage of the *Spiroplectammina* fauna, or one intermediate between it and the "Markley" fauna, seems characteristic of the main part of the Kreyenhagen shale, as this was originally defined by F. M. Anderson[55] on Reef Ridge; namely, the part between the unconformable Temblor-Kreyenhagen contact and first occur-

[49] J. A. Cushman and H. G. Schenk, "Two Foraminiferal Faunules from the Oregon Tertiary," *Univ. California Bull. Dept. Geol.*, Vol. 17, No. 9, pp. 305–24.

[50] D. D. Condit, *op. cit.*, p. 261.

[51] O. P. Jenkins, *op. cit.*, p. 146.

[52] D. Hughes and B. Laiming, "Notes on the Distribution of the Kreyenhagen Foraminiferal Fauna along the Western Border of San Joaquin Valley," paper read before the Pacific Section, Soc. of Econom. Paleont. and Mineral., April 3, 1933.

[53] C. C. Church, "*Foraminifera* of the Kreyenhagen Shale," *Mining in California*, Vol. 27, No. 2 (1931), pp. 202–13.

[54] *Op. cit.*, pp. 203–04.

[55] *Op. cit.*, pp. 163–68.

rence of *Pecten interradiatus* as recorded by Jenkins.[56] A foraminiferal assemblage closely related to the upper *Spiroplectammina* fauna has been found by the writer in samples collected by Jenkins at the localities listed in Table VI. With the *Foraminifera* present[57] in these samples were more or less abundant radiolarian tests.

TABLE VI

Locality	*Feet below Temblor Unconformity*	*Feet above First Occurrence of Pecten interradiatus*	*Feet above Kreyenhagen-Domengine Contact*
Canoas Creek	240–580	400–60	650–310
Garza Creek	345–445	100–0	290–190
Big Tar Canyon	150–540	640–250	845–455
1 mile SE. of Big Tar Canyon	0–495	495–0	700–205

The foraminiferal assemblage referred to by Hughes and Laiming as the lower stage of the *Spiroplectammina* fauna is apparently confined to the portion of the Kreyenhagen below the first occurrence of *Pecten interradiatus*. This portion constitutes the basal, sandy beds of the formation, and corresponds with the "transitional zone" of Jenkins.[58]

The assemblage present in the Domengine formation at its type locality near the Domengine ranch is decidedly different from the *Spiroplectammina* fauna. Examination, by the writer, of samples from the Domengine formation at various localities in the North Coalinga region shows that the formation contains a number of species[59] not recorded in the *Spiroplectammina* fauna, and contains few of the species typical[60] of the latter fauna. On the other hand, the list of species

[56] *Op. cit.*, chart facing p. 186.

[57] The most persistent *Foraminifera* appear to be: *Bathysiphon* sp., *Bathysiphon eocenica* Cushman & G. D. Hanna, *Bulimina* cf. *semicostata* Nutall, *Bulimina jacksonensis* Cushman, *Cassidulina subglobosa* H. B. Brady, *Cibicides ungeriana* (d'Orbigny), *Cibicides* sp., *Eponides advena* Cushman, *Eponides umbonata* (Reuss), *Globigerina* cf. *conglomerata* Schwager, *Gyroidina soldanii* d'Orbigny, *Gyroidina soldanii* d'Orbigny var. *octocamerata* Cushman & G. D. Hanna, *Haplophragmoides* sp., *Nodogenerina bradyi* Cushman, *Nodogenerina* aff. *lepidula* Schwager, *Nodosaria arundinea* Schwager, *Plectofrondicularia packardi* Cushman & Schenk (var.), *Robulus* sp., *Spiroplectammina* sp., *Spiroloculina* sp., *Uvigerina* cf. *jacksonensis* Cushman.

[58] *Op. cit.*, p. 181.

[59] *Cibicides alleni* (Plummer), *Cyclammina clarki* (Hanna), *Epistomina eocenica* Cushman & M. A. Hanna, *Eponides jacksonensis* (Cushman & Applin), *Globorotalia crassata* Cushman, *Globorotalia* aff. *cocoaenis* Cushman, *Globigerina triloculuaris* d'Orbigny, *Marginulina mexicana* (Cushman), *Marginulina mexicana* (Cushman) var. *nudicostata* (Cushman & G. D. Hanna), *Nodosaria latejugata* Gumbel, *Siphonina prima* (Plummer).

[60] *Bulimina obtusa*, *Cassidulina subglobosa*, *Cibicides cushmani*, *C. perlucida*, *C. ungeriana*, *Dentalina consobrina*, *D. sparsispinata*, *D. spinosa*, *Gaudryina trinitatensis*, *Gyroidina florealis*, *G. soldanii*, *Nodosaria* aff. *lepidula*, *Rhabdammina eocenica*, etc.

compiled by Hughes and Laiming suggests that the *Spiroplectammina* fauna (particularly its lower stage) is closely related to the foraminiferal assemblage identified by them in the type Tejon. Within the shales which contain the *Spiroplectammina* fauna, bentonite layers were cored in a well on the Jacalitos dome, in the well at the southeast end of Reef Ridge, and in a well near Devil's Den. This strengthens the resemblance to the type Tejon, in which the occurrence of bentonite has been noted by Hoots.[61]

Kreyenhagen shale at Kettleman Hills.—The Kreyenhagen shale, as it occurs at Kettleman Hills, is thus far known only from a few deep cores. Samples from the Kettleman North Dome Association's No. 38-34J between 8,547 and 8,703 feet, and from the Lillis Welsh well, between 9,600 and 9,800 feet, are believed to represent the *Leda* zone, although the only organic remains found were a few specimens of the same species of *Bolivina* and *Plectofrondicularia* present at the type locality, and some fish scales. Between 8,703 and 8,810 feet, well No. 38-34J furnished a good foraminiferal assemblage nearly identical with that of the *Leda* zone at its type locality. A microfauna characteristic of the *Uvigerina cocoaensis* zone has been found in cores from the Lillis Welsh well at depths of 9,968–9,972 feet, 10,024–10,033 feet, and 10,327–10,336 feet. The exact base of the *Uvigerina cocoaensis* zone in the Lillis Welsh well is unknown, but is tentatively placed where it would occur if the thickness of the zone were the same as where exposed in the North Coalinga region, and in the well at the southeast end of Reef Ridge.

From the lower part of the Lillis Welsh well only two cores, at depths of 10,831–10,835 feet and 10,925–10,927 feet, were secured. The upper core was shale, in the washed material of which were a few radiolarian tests and specimens of *Globigerina*, *Nodosaria*, *Robulus*, and *Spiroplectammina*. The lower core was ill-sorted medium to coarse sandstone barren of organic remains. In the writer's opinion this sand is to be correlated with the basal (sandy) part of the Kreyenhagen shale rather than with the Avenal or Domengine sandstone. Such a correlation is suggested by the mineralogical composition, which is characterized by a strong predominance of quartz, whereas the sandstone that occurs lower down in the section exposed along Reef Ridge is, according to von Estorff,[62] essentially feldspathic. Of 113 feet of strata penetrated by the Lillis Welsh well near its bottom,

[61] H. W. Hoots, "Geology and Oil Resources of the Southern Border of San Joaquin Valley," *U. S. Geol. Survey Bull. 812-D* (1930), p. 253.

[62] F. E. von Estorff, "Kreyenhagen Shale at the Type Locality, Fresno County, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 10 (October, 1930), pp. 1329–30.

only the lowest 33 feet were logged as solid sandstone, the larger portion being logged as alternating sandstone and shale.

Summary

Material from the upper part of the Kettleman Hills section, particularly from the upper Miocene, is rather meager. More cores were taken from beds described in this paper as the *Pecten andersoni* sand, and from the strata underlying this. Even in this part of the section, however, coring has not been sufficient to justify definite conclusions regarding some of the problems approached by the writer.

Interpretations which seem well supported by observed facts are as follows.

1. The Jacalitos is separated from underlying strata by a distinct break in deposition.
2. The microfauna in the upper part of the so-called "caving blue shale" or Reef Ridge formation shows that this part is much more closely related to the overlying Jacalitos than to the lower part of the "caving blue shale."
3. The studied material furnishes conclusive evidence against the theory of an unconformity between the so-called "brown shale" and the underlying *Pecten andersoni* sand.
4. The foraminiferal assemblage present in the so-called "600-foot shale," 600 feet below the top of the producing horizon, leaves no doubt that this shale is correlative with the Gould shale as exposed at Chico Martinez and Carneros creeks. The age of the upper part of the productive horizon at Kettleman Hills (the *Pecten andersoni* sand) is therefore younger than the type Temblor as defined by F. M. Anderson.
5. Comparison of the so-called "Temblor" penetrated by wells at Kettleman Hills, Lost Hills, and North Belridge with the type Temblor exposed in the Gould Hills, shows that, while the upper part of the formation (down to the base of the 'Button bed" sandstone) maintains nearly the same thickness between the Gould Hills and the northwestern end of the Kettleman Hills, the part of the Temblor underlying the "Button bed" sandstone thickens north of the Gould Hills, attains a maximum in the area embracing North Belridge, Lost Hills, and the Middle dome of Kettleman Hills, and then thins rather rapidly farther northwest.
6. The succession known as the Kreyenhagen shale is composed of two formations. The upper of these is microfaunally equivalent to the Bassendorf and the Keasy shales of the Oregon Coast Ranges, the age of which shales has been tentatively determined as lower Oligo-

cene. The lower formation is of probable Eocene age, and in its microfaunal content bears a close relationship to the "restricted Tejon" of Reed.

Conclusions not considered to be definitely proved are the following.

1. The boundary between the Pliocene and Miocene is not at the top of the so-called "caving blue," but is within the siltstone known by this name. Such a view finds support in the definitely Miocene aspect of the microfauna present in the lower part of the "caving blue," and in the Jacalitos (Pliocene) affinities of the microfauna of the upper part. This is particularly evident in the Petroleum Securities' Ladd No. 1, where a characteristically Jacalitos microfauna overlies siltstone which seems to represent the lowest beds of the "caving blue."

2. The unquestionably gradational contact between the "caving blue" and the underlying McLure (brown) shale in Kettleman Hills, North Belridge, and Belridge wells, suggests that the lower part of the "caving blue" (carrying the Miocene microfauna), is an upper member of the McLure shale. The writer has failed to find any evidence of disconformity between the two divisions.

3. In view of the obvious conformity of the "sporbo" shale (lower part of the "brown shale") with the underlying sand at Kettleman Hills, the tremendous variation in thickness of the "brown shale" is to be explained either by an extremely variable rate of deposition within a limited area, or by disconformity somewhere within the shale above the bentonite used as a marker in correlating wells at Kettleman Hills. The latter alternative seems most probable at this time, due to the apparently persistent position of layers rich in "sporbo" with reference to the bentonite; to the small thickness of the "sporbo" shale in the Guijarral and Jacalitos dome wells and in the Ohio Oil Company's Brix-Welsh No. 1; and to an absence of the "sporbo" shale in the well at the southeast end of Reef Ridge and in the sections exposed along Garza Creek and Canoas Creek. It should be admitted, however, that a more detailed study of the McLure outcrops along Reef Ridge would be needed to reach a definite conclusion in regard to the relation of the McLure shale and the "sporbo" shale.

4. The discovery of a bentonite layer far above the McLure-Temblor unconformity in the well at the southeast end of Reef Ridge indicates that the bentonite exposed on Reef Ridge may be different from the one used as a marker at Kettleman Hills. To prove this, more continuous coring within the "brown shale" of the Kettleman Hills would be required. The writer is inclined to believe that the

portion of the McLure shale which carries the bentonite at Reef Ridge is missing at Kettleman Hills due to disconformity between the McLure shale and the "sporbo" shale.

5. Material at hand gives no conclusive information as to the stratigraphic relation of the McLure shale to the Santa Margarita sandstone of the North Coalinga region. The sandy character of the McLure shale in the intermediate Guijarral area suggests the possibility, however, that the two may be different facies of one formation.

6. The "sporbo" shale at Kettleman Hills may be a part of the *Valvulineria californica* zone. This is suggested, first, by the lack of disconformity between this shale and the underlying *Pecten andersoni* sand, and, second, by the presence of the *Valvulineria californica* microfauna within the "sporbo" shale of the North Belridge section, this section being otherwise identical with the one at Kettleman Hills.

7. Comparison of the Kettleman Hills Miocene as a whole with the Miocene at Chico Martinez Creek indicates that the apparent disconformity between the "sporbo" shale and the McLure shale occurs within the *Gyroidina obesa-Frondicularia* succession. The fact that this succession is missing in some Miocene sections of California is indirect evidence favoring the presence of the supposed disconformity at Kettleman Hills.[63]

[63] After this manuscript was written, the writer has been informed by M. N. Bramlette that some "sporbo" (accompanied by abundant glauconite) are present in a sample taken by Bramlette at Big Tar Canyon. The beds carrying "sporbo" are only a few feet thick and occur at the top of the sandy shale zone that seems to be a basal part of the McLure. A 2-foot bentonite bed occurs in this sandy shale zone, 160 feet below the "sporbo" sample, and about 20 feet above the Temblor sandstone. In the light of the information furnished by the study of the Kettleman Hills section, there seem to be three possible explanations of the presence of "sporbo" in the McLure shale at Big Tar Canyon. These are: (1) that the "sporbo" shale does belong with the McLure shale, and the comparative thinness or even the absence of the former shale at various localities along Reef Ridge, as well as the tremendous variation in thickness of the "brown shale" at Kettleman Hills, results from an extremely variable rate in deposition of the shale; (2) that the "sporbo" found by Bramlette in a basal part of the McLure at Big Tar Canyon are redeposited from older beds; or (3) that the "sporbo" shale (or its supposed equivalent—the *Valvulineria californica* zone) represents a unit of sediments separated by disconformities both from the McLure shale above and the Temblor below.

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SAN JOAQUIN CLAY, CALIFORNIA[1]

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ABSTRACT

The post-Miocene sediments of the San Joaquin Valley, California, attaining a total thickness of nearly 14,000 feet, were deposited under varying conditions of marine, brackish, lacustrine, fluviatile, and subaerial sedimentation. Studies covering the southern end of the valley have demonstrated that these sediments may be divided into three main divisions on the basis of lithologic character, fossil content, and diastrophic history indicated. The three divisions comprise cartographic units of formational value.

The writers review the literature dealing with this stratigraphic section and designate the post-Miocene formations in the following manner.

Tulare formation (Pleistocene): lacustrine, fluviatile, and subaerial sediments.

San Joaquin clays (late Pliocene and early Pleistocene): lacustrine, brackish, and marine alternations.

Etchegoin sand (Pliocene): marine sediments.

The middle unit is discussed in detail and further differentiation of the section is shown by a study of the thermal facies.

A tentative correlation of the San Joaquin clay is attempted.

HISTORICAL REVIEW

F. M. Anderson[3] divided the post-Miocene beds of the Coalinga region into two divisions. The lower of these two divisions was again subdivided, making a total of three separate units. As these three units closely correspond with our present units, the names that Anderson proposed for his divisions are retained.[4]

F. M. Anderson described the Tulare formation from typical exposures in Kettleman Hills near the western shore of the extinct Tulare Lake. He stated that it is a fresh-water deposit, fully 1,000 feet thick, lying conformably on the "San Joaquin clays."

[1] Presented in preliminary form before the Pacific Section of the Association at Los Angeles, November 6, 1930. Revised manuscript received, November 11, 1933. The portion of this paper dealing with the geologic data of Kettleman Hills and the Coalinga district is the work of Galloway. Barbat is responsible for the other areas treated and the greater portion of the subject of "climatic zones." The tentative correlations are largely Barbat's conclusions. The writers wish to thank G. C. Gester for permission to publish their results. It was through his interest that this work was attempted. For the contribution of field data, advice, and criticisms the writers give credit and thanks to G. M. Cunningham, J. R. Dorrance, G. D. Hanna, C. J. Hesse, W. S. W. Kew, G. L. Knox, T. W. Koch, R. D. Reed, V. L. VanderHoof, and W. P. Woodring.

[2] Standard Oil Company of California.

[3] F. M. Anderson, "A Stratigraphic Study in the Mount Diablo Range, California," *Proc. California Acad. Sci.*, 3d ser., Geology, Vol. 2, No. 2 (1905), pp. 156-206.

[4] With this exception: that the singular forms—clay and sand—are substituted for Anderson's plural forms—clays and sands—where used as formational names: San Joaquin clay; Etchegoin sand.

The name "Etchegoin beds" was applied by Anderson to a series of clays, sands, and gravels having a "characteristic development" in the vicinity of the old Etchegoin Ranch, NW. ¼ of Sec. 1, T. 19 S., R. 15 E., M. D. B. & M. He divided the "Etchegoin beds" into the "San Joaquin clays," which compose the upper portion of the "Etchegoin beds," and the "Etchegoin sands," which compose the lower.

To the next older deposits, he gave the name "Coalinga beds." Originally, the "Coalinga beds" included formations now recognized as Temblor, Big Blue, Santa Margarita, and part of the redefined "Etchegoin beds." At a later date, F. M. Anderson[5] restricted his definition of "Coalinga beds" to "the lower portion of a series which is unconformably related to the older members of the Miocene." From his faunal list, revised thickness, and also his recognition of the "older" Miocene age of parts of his original "Coalinga beds," it appears that his intention was to restrict the name to a formation which others have regarded as a correlative of the Santa Margarita formation of the Salinas Valley. The contact between the "Coalinga beds" and the "Etchegoin beds" in the north part of the Coalinga district has been subsequently redefined by Arnold and Anderson[6] and Nomland.[7]

TABLE I

NAMES THAT HAVE BEEN USED FOR PARTS OF GEOLOGIC SECTION AT COALINGA

F. M. Anderson		*Ralph Arnold and Robt. Anderson*	*Jorgen O. Nomland*	*W. F. Barbat and John Galloway (present report)*
Tulare formation		Tulare formation	Tulare formation	Tulare formation
San Joaquin clays	Etchegoin beds	Etchegoin formation	Etchegoin formation: Upper	San Joaquin clay
Etchegoin sands		"*Glycimeris*" zone		Upper *Mulinia* bed
		Jacalitos formation	Lower	Etchegoin sand
Coalinga beds				Reef Ridge shale
		Santa Margarita (?)	Santa Margarita (?)	McLure shale

(Formation blocks not to scale)

[5] F. M. Anderson, "A Further Stratigraphic Study in the Mount Diablo Range of California," *Proc. California Acad. Sci.*, 4th ser., Vol. 3 (1908), pp. 1–40.

[6] Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District, California," *U. S. Geol. Survey Bull. 398* (1910), pp. 90–98.

[7] Jorgen O. Nomland, "Relation of the Invertebrate to Vertebrate Faunal Zones of the Jacalitos and Etchegoin Formations in the North of Coalinga Region, California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 9, No. 6 (1916), p. 79.

Arnold and Anderson[8] described the "Jacalitos" formation from exposures in Jacalitos Creek, South of Coalinga, as "unconformable with the shale mapped as the 'Santa Margarita (?).' " The beds overlying the "Jacalitos" formation were designated as the "Etchegoin" formation and the contact between the two was placed at the base of the "*Glycimeris*" zone. The distinction between the "Jacalitos" formation and the "Etchegoin" formation was made on the basis of faunal differences and a supposed local unconformity.

Nomland[9] found no faunal or lithologic basis for the "Jacalitos" formation. His conclusion is that the " 'Jacalitos' and the Etchegoin beds are closely linked in diastrophic history, and the former has therefore been included as a lower part of the Etchegoin." Of great significance is Nomland's conclusion that the "Jacalitos-Etchegoin" contact of Arnold and Anderson is without merit. However, it has remained for detailed mapping in Kettleman Hills to show the validity of a separation at a horizon higher than the "*Glycimeris*" zone.

GENERAL STATEMENT

The name, San Joaquin clay, is appropriate for the stratigraphic division bearing that name, as it is widely distributed in the central portions of the San Joaquin Valley and consists largely of clay beds in contradistinction to other formations in the basin. It is to be regretted that the literature pertaining to the San Joaquin clay includes casual allusions lacking designation of type section or precise definition. It is not surprising, for this reason, that many writers have overlooked the significance of the unit. In view of the prominent individuality of this unit, the many criteria that serve to distinguish it from adjacent units, and the natural basis for its delimitation, it is desirable to revive this unit as a formation.

The designation of a type locality for the San Joaquin clay was suggested to F. M. Anderson, who replied:

> When I gave the name "San Joaquin clays" to certain sediments north of Coalinga, in 1905, I was unable to determine the exact stratigraphic position of the formation except that it came above the marine Etchegoin. . . . I designated no type locality. It seems to me that under such circumstances, a worker who establishes the significance of such a group of sediments is perfectly justified in the selection of a representative locality which shows the relationships and to designate the same in some distinguishing manner. . . . The description of the new locality would, of course, be embodied in a new description of the formation. So long as such a name as this is not transferred

[8] Ralph Arnold and Anderson, Robert, *op. cit.*, pp. 96–124.

[9] Jorgen O. Nomland, "The Etchegoin Pliocene of Middle California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 10, No. 14 (1917), pp. 192–97.

to some other part of the geologic column, any such action should be sanctioned and accepted and I am heartily in favor of it.[10]

DESCRIPTION

The North dome of Kettleman Hills, Fresno and Kings counties, is chosen as the type locality of the San Joaquin clay, as the formation is there best exposed, most complete, most fossiliferous, and most accessible to study. At the type locality, the San Joaquin clay consists of strata that are extremely variable. Massive blue-gray and black clays, cross-bedded yellow-to-tan sandstones, thin dark brown sandstones, and white ashy members are present in rapid alternation. One reef-forming sandstone and minor diatomaceous and siliceous shales occur in this section. The beds, especially the clays, are gypsiferous. Several clay beds in the upper part of the formation have furnished drilling mud for the development of the Kettleman Hills oil field.

The formation is very fossiliferous, with fossil beds varying in thickness from 2 inches to 35 feet. Fossils of the following orders and classes have been found in the San Joaquin clay of Kettleman Hills: *Diatomaceae, Foraminifera, Anthozoa, Echinoidea, Brachiopoda, Pelecypoda, Gastropoda, Ostracoda, Cirripedia, Malacostraca, Pisces*, and *Mammalia*.

A typical section of the San Joaquin clay at the type locality is given on the following page.

The principal invertebrate zones of the San Joaquin clay at the type locality are the following.

1. The lowermost *Mya* zone. This zone is 60 feet above the base of the formation and is present on both flanks of the North dome. It is found sporadically on the southeast end of the North dome. The fauna of this zone is indicative of littoral and cool brackish conditions. A thin bed of Amnicolite (local name for rock composed largely of shells of small, fresh-water gastropods of the genus *Amnicola* or related forms), sometimes known as the "pavement bed," is a prominent feature of this zone.

2. The "*Natica*"-*Mya* zone. This zone is regularly 540 feet above the base of the formation and is exposed all around the North dome.

3. The *Pecten coalingaensis* zone. This zone varies from 1,100 to 1,470 feet above the base of the formation and is traceable on both flanks and around the northwest end of the North dome. A diastem occurs at the base of the zone. It is clearly exposed on the northwest end of the North dome, where the beds above and below have a con-

[10] F. M. Anderson, personal communication.

TYPE SECTION OF SAN JOAQUIN CLAY

Section 23, T. 22 S., R. 18 E., M. D. B. & M.

	Feet
Tulare formation: red-to-tan, massive sandstone, *Anodonta kettlemanensis* Arnold, *Amnicola, Planorbis* sp.	40
——— *Disconformity* ———	
Blue clay with gypsum	82
Amnicolite	7
Blue clay with gypsum	63
Ashy clay, *Mya japonica* Jay, *Solen sicarius* Gould, *Littorina mariana* Arnold; the uppermost "*Mya*" zone	25
Blue clay with gypsum	240
Gray sandy clay	130
Reddish tan quartz sandstone, *Arca trilineata* Conrad, *Calliostoma kerri* Arnold, *C. coalingensis* Arnold	4
Gray sandy clay	145
Red quartz sandstone, "*Natica*," *Ostrea* sp. (?), *Mytilus* sp. (?)	5
Gray sandy clay	12
Pebbly, dark brown, sandstone reef, vertebrates and *Pecten coalingaensis* zone fauna	35
——— *Diastem* ———	
Soft drab sand, *Fluminicola, Goniobasis kettlemanensis*	2
Tan sandy clay	208
Reddish tan weathering quartz sandstone, *Mya japonica* Jay	3
Sandy clay	310
Drab sands with darker colored sandstone lentils, *Dendraster* sp. (?)	60
Yellow and brown massive sandstone, "*Natica*," *Mya japonica* Jay, *Mytilus* sp. (?); the "*Natica-Mya*" zone	10
Blue clay with 12 feet of lenticular blue-gray "vivianitic" sandstone at top	105
Tan and brown indurated sandstone, *Mya japonica* Jay	3
Blue clay with gypsum	115
Brown sandstone, *Cardium meekianum* Gabb	2
Sandy clay	60
Blue and tan clay, a few lenses of "vivianitic" sandstone	90
Ashy blue-gray "vivianitic" sandstone	10
Blue and tan clay and sandy clay	75
Tan-to-brown coated-grain sandstone, *Mya japonica* Jay, *Solen sicarius* Gould, *Calyptraea* sp. (?), *Littorina* cf. *mariana* Arnold, et cetera	4
Blue clay	35
Lenticular blue-gray, "vivianitic" sandstone	20
"Upper *Mulinia*" zone of Etchegoin sands	
Total thickness of San Joaquin clay	1,860

tact that is irregular and weaving. The diastem is not well exposed in other parts of the type locality. The fauna of the *Pecten coalingaensis* zone is suggestive of warm, shallow, brackish-marine conditions as many of the forms are closely related to Recent Gulf of California species. Fragmentary cetacean material has been found in certain parts of the *Pecten coalingaensis* zone. The *Pecten coalingaensis* zone grades rapidly into warm lacustrine beds, both laterally (toward the south) and vertically. A well preserved mastodon head, *Pliomastodon vexillarius* Matthew, has been excavated from clays underlying the *Pecten coalingaensis* zone.

4. The uppermost *Mya* zone. This zone is 1,640–2,140 feet above the base of the formation. The fauna of this zone is indicative of cold, brackish-water and littoral conditions.

RELATION TO OVERLYING BEDS

The San Joaquin clay is unconformably overlain by the Tulare formation. The contact is well exposed on the northeast side of the Kettleman Hills and is characterized by irregularities and differential removal of recognizable beds of the underlying formation. In certain areas outside of the Kettleman Hills, the Tulare formation overlaps the San Joaquin clay and rests on nearly all the older formations. Subsurface correlations in the Belridge district of Kern County show the Tulare formation to overlap the San Joaquin clay and rest in marked angular unconformity upon the Etchegoin sands. In the Bacon Hills, west of Belridge, a discordance of nearly 20° has been measured between the Tulare and the San Joaquin clay.

The basal bed of the Tulare formation in the Kettleman Hills is a prominent, reddish yellow, fossiliferous sandstone, 50–100 feet thick, containing a diversified lacustrine molluscan fauna. Overlying the basal Tulare member is 500–3,300 feet of poorly sorted, fluviatile sands, gravels, and sandy clays. An upper lacustrine member, not clearly defined in Kettleman Hills exposures, but recognized by its faunal and floral content in well sections east of the Kettleman Hills, attains a thickness of more than 600 feet. The diatom *Stephanodiscus* is present in the upper lacustrine member in rock-forming abundance.

The Tulare formation contains considerable quantities of reworked Miocene rocks, particularly fragments of "Monterey shale." In the southwestern part of the San Joaquin Valley, zones of specifically identifiable, reworked Miocene *Foraminifera* are recognized in Tulare beds. The San Joaquin clay and older formations do not contain recognizable Miocene elements except locally, as at the northeast edge of the Temblor Range, where the "Monterey shale" formed a shore line for them.

The Tulare formation is unconformably overlain by Recent alluvium. As determined from well sections east of the Kettleman Hills the alluvium averages 500–600 feet in thickness. A maximum of 880 feet of this material, probably occurring in some ancient river channel, has been found northwest of Tulare Lake. The alluvium is characterized by buff sands and muds of fluviatile origin and in the central portions of the extinct Tulare Lake by olive gray clays and sandy clays with lacustrine molluscan remains.

RELATION TO UNDERLYING BEDS

The San Joaquin clay rests with apparent conformity on the Etchegoin sands in the Kettleman Hills. The highest member of the Etchegoin sand has been described as the "upper *Mulinia*" zone from the abundant occurrence of *Mulinia densata* Conrad in this bed. The top of the upper *Mulinia* zone is chosen as the base of the San Joaquin clay because this horizon marks an important lithologic and faunal change. This change is caused by a fundamental metamorphosis of the physical environment. For purposes of geologic mapping, the top of the upper *Mulinia* zone is well chosen as a contact, as it is easily recognized in the field or in well cores, and the horizon is recognizable throughout a wider area than any other Pliocene horizon.

In general, the Etchegoin sand consists of massive blue and brown sandstones, poorly sorted sandy shales, and pebble-conglomerates. A notable feature of the Etchegoin sand is the poor sorting of the rocks as contrasted with the San Joaquin clay. This is particularly apparent in well-core material where attention is focused on the thicker average members of each formation rather than on the thinner prominent beds that attract attention in field observation. The sediments of the San Joaquin clay exhibit the perfect mechanical sorting of the lacustrine and brackish-water environments, while the Etchegoin sand sediments have the characteristic less perfect sorting of normal marine conditions. The average grain size of the Etchegoin sand is noticeably larger than that of the San Joaquin clay and the deposits of the former formation tend to be more indurated. Many exceptions occur and the fossils are considered to offer the most reliable means of separating the two formations.

The faunal break at the "upper *Mulinia*" zone is due, unquestionably, to changing environments. Many species of marine invertebrates, common below the top of the "upper *Mulinia*" zone, are absent in the San Joaquin clay above. Brackish-water forms are much less common below the "upper *Mulinia*" zone than above it. Fresh-water organisms make their first appearance in the section above the "upper *Mulinia*" zone. The "upper *Mulinia*" zone horizon marks the end of a long period of open marine deposition and the initiation of a period of fluctuating conditions with brackish-water and fresh-water sedimentation predominating over marine. The event that transpired at this time, resulting from climatic change, earth movements, or change in sea-level elevation, can be ascribed either directly or indirectly to diastrophism. It is interesting to note that the temperature conditions, as evidenced by the faunas of the two formations, underwent a change from relatively warm and equable, during the deposi-

tion of the Etchegoin sand, to alternating cool and warmer, during the San Joaquin clay time. These alternating periods of cool and warmer temperatures are strongly suggestive of glacial and interglacial phenomena. (Important papers on the fossils of the Etchegoin sand and the San Joaquin clay are listed in the Bibliography at the end of this article.)

The Etchegoin sand is 4,730 feet thick in the North dome of Kettleman Hills. Of this thickness, only the upper 540 feet is exposed. The basal member of the Etchegoin sand is characterized by fossil wood and plant remains throughout much of the Coalinga district and was probably deposited under terrestrial conditions. On Reef Ridge, southwest of the Kettleman Hills, the Etchegoin sand rests with marked unconformity on the Reef Ridge shale, an uppermost Miocene formation.

DISTRIBUTION

Middle dome of Kettleman Hills.—The San Joaquin clay is present in the Middle dome and, except for a higher clay content, is similar to the same formation in the North dome. On the northeast flank, the formation is slightly more than 1,800 feet thick, but reaches its greatest thickness in this area on the southwest flank, where a thickness of 2,635 feet has been measured.

The lowermost *Mya japonica* bed is not well defined and small, fragile *Mya* occur in the top of the upper *Mulinia* zone.

In the northwest end of the dome, the occurrence of the "*Natica*"-*Mya* bed is similar to its occurrence at the North dome and is 540 feet above the upper *Mulinia* zone. Elsewhere, this interval becomes irregular.

The *Pecten coalingaensis* zone is 1,140 feet above the base of the formation on the northeast flank and 1,470 feet on the southwest flank. The zone is composed of conglomeratic rock and in some localities white siliceous shale fragments are abundant.

The uppermost *Mya japonica* zone is prominent on both flanks of the dome. It is overlain by clays of varying thickness. On the northeast flank, the top of the uppermost *Mya japonica* zone is about 100 feet from the base of the Tulare formation, but on the southwest flank, it is about 450 feet below this contact.

Jacalitos and Kreyenhagen Hills.—The San Joaquin clay of the Jacalitos and Kreyenhagen Hills is very similar to that of the type locality. The lowermost *Mya* zone, the *Pecten coalingaensis* zone, and the upper *Mya* zone, are recognized. The formation rests conformably on the upper *Mulinia* zone, but is unconformably overlain by the

basal lacustrine member of the Tulare formation. The thickness of the San Joaquin clay, measured on the south flank of the Jacalitos dome, is more than 2,000 feet. An extremely rapid convergence, at the base of the formation, takes place toward the northwest. In the southwest quarter of Sec. 29, T. 21 S., R. 15 E., the *Pecten coalingaensis* zone is 1,800 feet above the base of the formation. One and two-tenths miles northwest, it is only 300 feet above the base of the formation.

Alcalde Hills.—A partial section of the San Joaquin clay is present in the Alcalde Hills, northwest of the Jacalitos dome. The formation is overlapped by alluvium a few feet above the *Pecten coalingaensis* zone. A local unconformity or overlap occurs at the base of the formation. This may be seen near the west line of Sec. 7, T. 21 S., R. 15 E. The upper *Mulinia* zone of the Etchegoin sand and a few basal beds of the San Joaquin clay are missing at the unconformity. Northward from this point, the San Joaquin clay rests on beds that are more than 100 feet stratigraphically below the top of the "*Glycimeris*" zone, or at least 230 feet stratigraphically below the upper *Mulinia* zone. Near the middle of the south line of Sec. 36, T. 20 S., R. 14 E., the unconformity is exposed approximately 50 feet above the top of the "*Glycimeris*" zone. The difference in dip above and below the unconformity is about 3°.

Anticline Ridge.—On Anticline Ridge, about 16 miles northeast of Coalinga, the San Joaquin clay is exposed and carries a higher percentage of clay than at other places in the district. The upper *Mulinia* zone of the Etchegoin sand is exposed in the northeastern part of the SW. ¼ of the SW. ¼ of Sec. 34, T. 19 S., R. 15 E. Here, the zone contains *Mulinia densata* Conrad, *Glycimeris septentrionalis* (Middendorff), *Dendraster gibbsii* (Remond), and small *Tamiosoma* (?). There is an unconformity of merely local character approximately 440 feet above the top of the upper *Mulinia* zone. This is exposed in two localities: one near the west line of the NW. ¼ of Sec. 25, T. 19 S., R. 15 E., on the Coalinga-Hanford highway; and the other on the east bank of an intermittent stream at approximately the NW. cor. of Sec. 1, T. 19 S., R. 15 E. Beds below the unconformity strike north and south and dip 15° east; above, they strike N. 5° W. and dip 13° east. The basal beds of the San Joaquin clay are, in places, overlapped in a northwesterly direction.

The *Pecten coalingaensis* zone is present on Anticline Ridge. It is exposed near the south line of Sec. 12, T. 20 S., R. 15 E. and extends northwestward and northeastward on the flanks of the Coalinga anticline.

Sporadic exposures of beds bearing *Amnicola*, similar to those of the basal Tulare lacustrine member, prove the presence of the Tulare formation on the east flank of Coalinga anticline.

Southern San Joaquin Valley.—In the southern San Joaquin Valley, the Tulare formation almost everywhere rests on Miocene and older rocks, leaving only a few widely separated exposures of the San Joaquin clay. Thin parts of the San Joaquin clay are exposed in the Bacon Hills, near McKittrick; near Sunset; and in the San Emigdio district, all in Kern County. Our knowledge of the San Joaquin clay in the southern San Joaquin Valley is derived largely from well cores.

The first attempt to correlate the post-Miocene sediments of the southern San Joaquin Valley with the Coalinga section was made by Arnold[11] and Arnold and Johnson.[12] They proposed the name "McKittrick formation" for a series of gravels, sands, and clays, lying unconformably above the Monterey and Santa Margarita (?) and typically exposed one-half mile south of the town of McKittrick.

In 1920, Pack[13] referred to the McKittrick formation as the McKittrick group and included two formations within it. The lower portion of the McKittrick group, comprising beds deposited chiefly in marine waters, was correlated with the Etchegoin formation, and the upper part, deposited under fresh and brackish water in part and in part subaerial, was referred to as the "Paso Robles" formation. The "Jacalitos" formation of the Coalinga region was included in the Etchegoin formation of the southern San Joaquin Valley.

Pack considered his "Paso Robles" beds as being nearly the equivalent of the Tulare formation, but preferred the name "Paso Robles" because he was of the opinion that the two names were synonymous, the name "Paso Robles" antedating the name "Tulare." Although the Tulare formation may be contemporaneous in part with the Paso Robles formation of the Salinas Valley, the name Tulare should not be abandoned. The two formations were deposited in two distinctly separate basins of deposition and it is not possible to correlate them by ordinary criteria.

Pack's "Paso Robles" formation included the Tulare formation and varying amounts of the San Joaquin clay. The present study

[11] Ralph Arnold, "Paleontology of the Coalinga District, Fresno and Kings Counties, California," *U. S. Geol. Survey Bull. 396* (1909), p. 22.

[12] ——— and Harry R. Johnson, "Preliminary Report on the McKittrick-Sunset Oil Region, Kern and San Luis Obispo Counties, California," *ibid., Bull. 406* (1910), pp. 74–89.

[13] Robt. W. Pack, "Sunset-Midway Oil Field, California," *U. S. Geol. Survey Prof. Paper 116* (1920), pp. 43–51.

shows that it has no value in the San Joaquin Valley geologic time-table and its use should be discontinued in this region.

With the aid of many cored wells, it is possible to construct a generalized section of the San Joaquin clay in the southern San Joaquin Valley. These wells are distributed from the Midway district to the San Joaquin Valley floor, near the town of Shafter, Kern County, California. The section follows.

	Feet
Tulare formation: buff sand, powdery gray sand and silt, green to rust-colored clay, peaty clay, and thin limestones. Chiefly unfossiliferous (except for reworked Miocene *Foraminifera*) and scattered *Gonidea coalingaensis* Arnold, *Goniobasis* n. sp. (related to *G. kettlemanensis* Arnold), *Anodonta kettlemanensis* Arnold, and fresh-water gastropods near base of formation	0–2,000
Conformity—basinward	*Unconformity—marginal*
"A" zone of San Joaquin clay: tan clay, *Physa wattsi* (large ornate variety) Arnold, *Fluminicola* cf. *seminalis* Hinds, *Amnicola* cf. *andersoni* Arnold, *Anodonta kettlemanensis* Arnold, *Carinifex marshalli* Arnold (?), *Ostrocoda*	0–1,000
"First *Mya-Elphidium* zone," equivalent to "upper *Mya* zone" of Kettleman Hills: blue clay, *Mya japonica* Jay, *Macoma balthica* (Linnaeus) *M. inquinata affinis* Nomland, *Lucina californica* Conrad, *Elphidium hughesi* Cushman and Grant	50
"B" zone of San Joaquin clay: green clay and gray silt thinly interlaminated, practically unfossiliferous, a single jaw of the vole *Mimomys primus* (Willson) found in this zone	1,150
"Second *Mya-Elphidium* zone": blue clay, fauna nearly identical with "First *Mya-Elphidium* zone"	120
"C" zone of San Joaquin clay: brown clay.	
Warm-temperate marine finger, gray and brown clay, *Laevicardium centifilosum* (Carpenter), *Corbula gibiformis* Grant and Gale, *Clypeaster* (?)	30
Lacustrine brown clay, abundant *Ostracoda*, *Anodonta* sp., *Viviparus* sp. ?, *Goniobasis kettlemanensis* Arnold	340
Upper *Scalez* zone, brown clay with *Scalez petrolia* Hanna and Gaylord, and other forms listed in previous sub-zone	20
Brown clay, in many places grades into lenticular sands, *Goniobasis kettlemanensis* Arnold, *Anodonta* sp., *Ostracoda*, et cetera	170
Total thickness of "C" zone	560
"Third *Mya-Elphidium* zone": blue clay, *Mya japonica* Jay, *Psephidia* sp., *Macoma inquinata affinis* Nomland, *Elphidium hughesi* Cushman and Grant, *Discorbis* sp. (living—Puget Sound)	100
"D" zone of San Joaquin clay: green clay and gray silt, thinly interlaminated, practically unfossiliferous	325
"E" zone of San Joaquin clay	
"Fourth *Mya-Elphidium* zone," blue clay, *Mya japonica* Jay, *Cryptomya californica* (Conrad), *Psephidia* sp., *Discorbis* sp., *Elphidium hughesi* Cushman and Grant, et cetera	100
Laminated "E" zone, chiefly green clay and gray silt thinly interlaminated	280
Marine finger, gray clay, abundant *Cryptomya californica* Conrad, *Nuculana* sp. (?), *Psephidia lordi* (Baird), *Discorbis* sp.	15
"*Pecten-Mytilus*" zone, brownish gray shell marl, very abundant *Pecten eldridgei* Arnold, *Mytilus* sp.	10
Lower *Scalez* zone, brown clay with *Scalez petrolia* Hanna and Gaylord	20
Brown clay with *Amnicola* sp. and *Ostracoda*	50

"Fifth *Mya-Elphidium* zone," blue clay, *Mya japonica* Jay, *Elphidium hughesi* Cushman and Grant, *Discorbis* sp., et cetera	20
Total thickness "E" zone	495
Total thickness San Joaquin clay	3,300

Upper *Mulinia* zone of Etchegoin sand
(large marine, invertebrate fauna)

Most of the zones and members of the San Joaquin clay have remarkable persistence from north of Kettleman Hills on the north to the vicinity of the town of Maricopa on the south. The San Joaquin clay and Etchegoin sand "shore-line" abruptly against the Temblor Range on the southeast. The San Joaquin clay is typically developed in the Buttonwillow and Semitropic districts of Kern County, but east of this area it grades laterally into terrestrial deposits commonly assigned to the Kern River series.

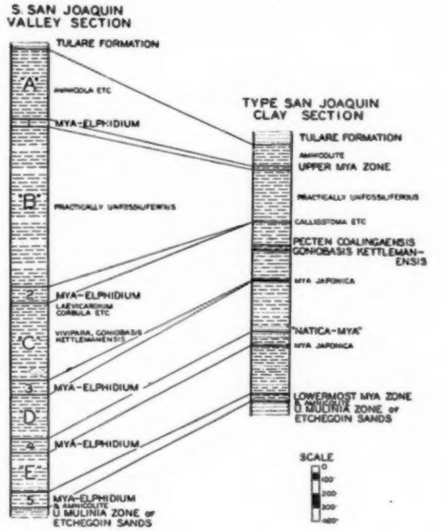
The San Joaquin clay of the southern San Joaquin Valley may be correlated with the type section in the Kettleman Hills as is shown in Figure 1. In the direction of Kettleman Hills and the Coalinga district, zones that are brakish in the southern area become more marine, and fresh-water zones become more brackish. The outlet of the San Joaquin Basin to the sea, at this time, was, therefore, near the Coalinga district. A study of the area surrounding Coalinga shows that the outlet lay through the Waltham Valley-Priest Valley break in the Diablo Range.

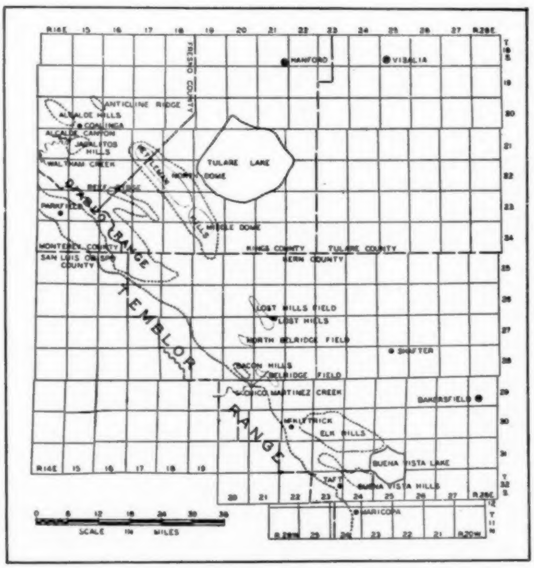
Several unconformities of local character exist at or near the base of the San Joaquin clay. The unconformities of the Alcalde Hills and Anticline Ridge have been described. In addition to these, the *Pecten-Mytilus* zone, in the Buena Vista Hills of Kern County, is in unconformable relationship to underlying beds; a local unconformity at approximately the same horizon occurs in the Elk Hills on the east; and an unconformity or overlap occurs near the upper *Mulinia* zone in Buena Vista Hills and near McKittrick.

CLIMATIC ZONES OF POST-MIOCENE FORMATIONS

World-wide correlations of post-Miocene sediments are now being attempted by the comparison of thermal facies and climatic changes. As climatic zone data in particular areas will be in great demand, it is felt that the climatic conditions of the San Joaquin Basin should be adequately considered.

Any interpretation that may be given to the thermal facies of the post-Miocene sediments must be made in consideration of the paleogeography of the basin. For this reason, a picture of the San Joaquin Basin as it existed in the Pliocene and the Pleistocene is drawn from the best available information.


S. SAN JOAQUIN VALLEY SECTION
TULARE FORMATION
"A"
MYA-ELPHIDIUM
"B"
2
MYA-ELPHIDIUM
LAEVICARDIUM CORBULA ETC
VIVIPARA, CONIOBASIS KETTLEMANENSIS
"C"
3
MYA-ELPHIDIUM
"D"
4
MYA-ELPHIDIUM
"E"
5
MYA-ELPHIDIUM & AMNICOLITE
U MULINIA ZONE or ETCHEGOIN SANDS
TYPE SAN JOAQUIN CLAY SECTION
TULARE FORMATION
UPPER MYA ZONE
CALLISTOMA ETC
PECTEN COALINGAENSIS
CONIOBASIS KETTLEMAN-ENSIS
MYA JAPONICA
"NATICA-MYA"
MYA JAPONICA
LOWERMOST MYA ZONE
U MULINIA ZONE or ETCHEGOIN SANDS
SCALE
0
100'
200'
300'
400'


R14E
R28E
FRESNO COUNTY
HANFORD
VISALIA
ANTICLINE RIDGE
COALINGA
ALCALDE CANYON
WALTHAM CREEK
TULARE LAKE
DOME
PARKFIELD
RANGE
MIDDLE DOME
MONTEREY COUNTY
KINGS COUNTY
TULARE COUNTY
SAN LUIS OBISPO COUNTY
KERN COUNTY
TEMBLOR
LOST HILLS FIELD
LOST HILLS
NORTH BELRIDGE FIELD
SHAFTER
BELRIDGE FIELD
MARTINEZ CREEK
BAKERSFIELD
RANGE
ELK HILLS
BUENA VISTA LAKE
TAFT
BUENA VISTA HILLS
MARICOPA
SCALE IN MILES

FIGS. 1 and 2

Water bodies that have existed in the San Joaquin Basin since the Miocene have been uniformly shallow and have rarely exceeded a width of 36 miles and a length of 120 miles. The air-line distance from the southwestern side of the basin to the ocean was 50–60 miles (actually greater during part of post-Miocene time because of subsequent shortening by folding), but was more than twice that distance by the narrow, devious, intermittently closed water channel connecting the two. Several ranges of mountains, in which older rocks are now exposed, stood at unknown heights between the basin and the ocean.

South of the San Joaquin Basin, stood the old, positive, high land mass of the San Emigdio-Tehachapi mountain system which has been yielding its boulders to the basin since Miocene time. On the east and northeast, stood the Sierra Nevada, the geomorphic history of which indicates growth from relatively early times and principally in late Tertiary and Quaternary periods. This is verified by the character of the sediments piled at the western base of the range.

When viewed in its larger aspects, the San Joaquin Basin is an integral part of the great Sierra Nevada block, bounded on the east by the fault of the Sierra scarp and on the west by the San Andreas fault system. The history of this block since the Miocene (and earlier) has been one of rotation. Hinging on an axis, located near the present western boundary of the massif, the eastern portion was tilted upward to lofty heights as the western portion was swung downward, while receiving more than 14,000 feet of shallow-water deposits.

If this is a fair picture of conditions as they existed, it is quite apparent that water temperatures of the San Joaquin Basin were less influenced by ocean temperatures and more affected by land temperatures of the surrounding ranges than the several California coastal post-Miocene basins. Thus, in a period of Sierran glaciation it is reasonable to expect a chilling of the waters of the basin, regardless of the temperatures of the ocean outside. Glacialogists are invited to consider the testimony of the San Joaquin sediments, as it may supplement their study of the too impermanent glacial landscape.

THERMAL ZONES OF ETCHEGOIN SAND

The faunas of the Etchegoin sand are indicative of fairly warm conditions. The lowest Etchegoin sand faunal zone, the *Chione elsmerensis* zone of Nomland,[14] has been recognized as a warm-water zone. The faunas between the *Chione elsmerensis* zone and the upper *Mulinia* zone show slow progressive cooling.

[14] Jorgen O. Nomland, *op. cit.*, pp. 210–11.

THERMAL ZONES OF SAN JOAQUIN CLAY

The appearance of *Mya japonica* Jay a short distance above the upper *Mulinia* zone can be taken to indicate a fairly abrupt chilling of the basin. The several brackish-water zones of the San Joaquin clay that are characterized by an abundance of this species can be regarded as having been much cooler than any known conditions in the Etchegoin sand, and also cooler than the waters of this latitude in California at present.

The faunas of the *Pecten coalingaensis* zone and the *Pecten eldridgei* zone (*Pecten-Mytilus* zone) are noticeably warmer than the faunas of the *Mya japonica* zones and warmer than ocean temperatures of this latitude in California at present.

The climatic conditions during the deposition of the fresh-water zones cannot be determined as readily, because of more limited knowledge. In the case of *Goniobasis kettlemanensis* Arnold and several other forms, indirect evidence as to temperature is present. These forms are found closely associated with warm-water *Pecten coalingaensis* zone species. Other species have affinities with recent forms found living in Klamath Lake and Lahontan remnants, and might be living in the San Joaquin Valley to-day, if it were not for their local extinction in periods of interglacial desiccation.

A close correlation between the color of the sediments and their contained thermal faunules has been observed. Almost without exception, warm-water organisms are present in clays of brown color and cool-water organisms are present in blue or blue-green colored clays. There has been an excellent opportunity to observe these facts in connection with the many continuously cored wells of the San Joaquin Valley. In parts of the section that appear too cold to support any life that the ocean might offer, the clays are bright green. The color of the clays is almost certainly influenced by the temperatures at the time of deposition. The brown coloration is indicative of the presence of carbon and ferric iron while the blue and green colors are indicative of ferrous iron and possibly some preserved chlorophyll pigment. Core material of the green and blue clays has been observed to oxidize to ocherous and olive tints in comparatively brief periods upon exposure to the present surface temperatures. This leads to the already widely accepted conclusion that, when the chemical influence of organic matter is negligible, oxidation of bottom sediments is most apt to happen in a warm environment and reduction in a cool environment. Pyrite, fossil plants, highly organic deposits, or anything that might point to any considerable biochemical action are relatively rare in the San Joaquin clay. Therefore, in the absence of

diagnostic faunal evidence as to thermal conditions, the color of the clays can be used as a criterion.[15]

A thermal scale for the various parts of the San Joaquin clay is here given.

Zone	*Temperature*	*Remarks*
"A" zone	Temperate	Clays, neutral-to-tan colored. Fresh-water temperate fauna
Upper *Mya* zone. "First *Mya-Elphidium* zone"	Cool	Clays, blue-colored. Circumboreal fauna
"B" zone	Cold—probably glacial	Clays, green-colored. Fossils practically absent. Peculiar rhythmically interlaminated silt and clay character suggestive of alternations in carrying power of entering streams. Such alternations are most perfectly developed under control of glacial melt and freeze. Possibility that this interlamination has resulted from effect of tides has been entertained and dismissed. Nature of basin and its opening, thickness of individual lamina, and complete absence of laminae in zones of brackish-water fossils preclude tidal hypothesis
"Second *Mya-Elphidium* zone"	Cool	Clays, blue-colored. Fauna ecologically similar to "First *Mya-Elphidium* zone"
"C" zone	Warm	Clays, brown-colored. Contains warm-brackish-marine *Pecten coalingaensis* zone fauna and warm-freshwater *Goniobasis kettlemanensis* and *Viviparus* fauna
"Third *Mya-Elphidium* zone"	Cool	Clays, blue-colored. Species identical with "First" and "Second *Mya-Elphidium* zones"
"D" zone	Cold. Probably glacial.	Clays, green-colored. Fossils practically absent. Laminated as in "B" zone
"E" zone	Variable as shown below	
Sub-zones of "E" zone		
"Fourth *Mya-Elphidium* zone"	Cool	Blue clay. Fauna same as other "*Mya-Elphidium* zones"
"Laminated member"	Cold. Brief glaciation (?)	Green-colored clay. Laminated like "B" zone
"*Pecten-Mytilus* and *Scalez* zones"	Warm	Brown-colored clays. Contains warm-brackish *Pecten eldridgei* Arnold and warm-fresh-water species common to warm "C" zone
"Lowermost *Mya* zone"	Cool	
"Fifth *Mya-Elphidium* zone"		Blue-colored clay. Contains brackish-water species common to other "*Mya-Elphidium* zones." Local extinctions

THERMAL ZONES OF TULARE FORMATION

The Tulare formation has fewer evidences of climatic zones than the San Joaquin clay. The basal lacustrine member of the Tulare formation contains several species related to cooler recent species and the general aspect of the fauna is cool-temperate. The middle portion

[15] Attention has been called to the green color of the finer lacustrine sediments of the late glacial Manix Lake in the Mojave Desert: J. P. Buwalda, "Pleistocene Beds at Manix in the Eastern Mojave Desert Region," *Univ. California Bull., Dept. Geol. Sci.* Vol. 7, No. 24 (1914), pp. 443–64.

of the Tulare formation is composed largely of fluviatile sands and gravels with no definite indication of temperature. The top portion of the Tulare formation contains lacustrine members with a very small lacustrine fauna. The local extinction of many of the lower Tulare mollusks may be due to mid-Tulare desiccation.

The lacustrine deposits of the early Tulare are most widespread and occur on areas that are now structurally high, such as Kettleman Hills and McKittrick. Thus the ancient early Tulare lake is believed to have very greatly exceeded the limits of historical Tulare lake. As evidenced by cored wells in the Tulare lake basin, the ancient mid-Tulare lake was decreased to a small fraction of the extent of the earliest lake and did not exceed the limits of historical Tulare lake.

The spread of the ancient late-Tulare lake is marked by beds of fresh-water diatoms that are continuous for many miles beyond the historical limits of Tulare lake. The well records of the Tulare Lake gas field show a regressive shoreline sandstone between the upper and lower portions of the upper Tulare lacustrine member. This would appear to indicate that the ancient late-Tulare lake had two advances with an intermediate retreat.

The advances and retreats of ancient lakes in western North America have been directly correlated with advances and retreats of the glaciers in this area. The writers see no reason to believe that the advances and retreats of the ancient Tulare lake should be otherwise correlated. Thus a period of glaciation is referred to the early Tulare, a period of interglaciation to the middle Tulare, and a period of glaciation to the late Tulare

THERMAL CHARACTER OF ALLUVIAL DEPOSITS

The Alluvium, as seen in well cores away from Tulare Lake, consists of buff-to-light brown silts and muds without any traces of aquatic animals. This material is obviously non-lacustrine in origin and is believed to have resulted from deposition on flood plains. The color of the sediments is ascribed to oxidation resulting from alternate wetting and drying with the seasonal high- and low-water stages of the major rivers. The Alluvium of the central portion of the recently extinct Tulare Lake consists of interbedded fine sands and clays with fresh-water shells (chiefly *Anodonta*). This material shows abundant evidence of having been deposited under semi-continuous lacustrine conditions.

The extent of Tulare Lake in Alluvial time was no greater than the extent in late historic time. Thus the entire Alluvial epoch is placed in the post-Glacial period.

AGE DETERMINATION AND CORRELATION OF SAN JOAQUIN CLAY

HISTORY OF CORRELATION

The "Jacalitos" and "Etchegoin" formations, as mapped by Arnold and Anderson,[16] were correlated with the San Pablo group of northern California. This correlation was based chiefly on lithology. Upon this correlation and "Lyell percentage method" application, Arnold[17] regarded the "Etchegoin" formation as of Miocene age. Bruce Clark[18] found the fauna of the San Pablo to be distinctly older than the "Etchegoin" and also formed the opinion that it is older than the "Jacalitos."

Nomland[19] placed little faith in the "Lyell percentage method" as it had been used previously to determine the age of the "Jacalitos" and "Etchegoin" formations. He placed both formations (now divided into Etchegoin sand and San Joaquin clay) in the Pliocene.

Vertebrate material from the Etchegoin sand and San Joaquin clay has been found in the North Coalinga region. J. C. Merriam[20] described *Pliohippus* from the Etchegoin sand and determined the Pliocene age of this formation. He also described a fauna consisting of a mastodon, two different species of camel, a cervid, and a large horse, *Equus* (?), or possibly *Pliohippus* (?), from the San Joaquin clay. The very recent aspect of at least a part of this fauna has cast doubt upon the occurrence of the fossils. The question has been raised whether these remains may not occur in terrace material, but Nomland[21] has clearly shown that they are from the San Joaquin clay.

Grant and Gale[22] have made a most important contribution to the study of the Pliocene and Pleistocene periods of California. The various Pliocene and Pleistocene units of the Ventura, Los Angeles, and San Diego basins are correlated and fitted together to form a sort of

[16] Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District, California," *U. S. Geol. Survey Bull. 398* (1910).

[17] Ralph Arnold, "Paleontology of the Coalinga District, Fresno and Kings Counties, California," *U. S. Geol. Survey Bull. 396* (1909), p. 45.

[18] Bruce L. Clark, "Fauna of the San Pablo Group of Middle California," *Univ. California Bull. Dept. Geol. Sci.*, Vol. 8, No. 22 (1915), pp. 434–43.

[19] Jorgen O. Nomland, *op. cit.*, pp. 225–27.

[20] J. C. Merriam, "Tertiary Vertebrate Faunas of the North Coalinga Region," *Trans. Amer. Philos. Soc.*, Vol. 22 (1915), Pt. 3.

[21] Jorgen O. Nomland, "Relation of the Invertebrate to the Vertebrate Faunal Zones of the Jacalitos and Etchegoin Formations in the North Coalinga Region, California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 9 (1916), pp. 83–84.

[22] U. S. Grant, IV, and Hoyt Rodney Gale, "Pliocene and Pleistocene Mollusca of California, Together with a Summary of the Stratigraphic Relations of the Formations Involved," *Memoirs San Diego Soc. Nat. Hist.*, Vol. 1 (1931), pp. 7–77.

standard California section. Without inferring that equally detailed studies were carried on in the San Joaquin Basin and other parts of California, they attempted, from existing knowledge of these areas, correlations with their type section. Their correlations were made after full weight was given to first appearances and extinctions of species, climatic changes, identity of species in the several basins, and sedimentary cycles. As conditions were more alike from basin to basin in early post-Miocene time, becoming increasingly dissimilar as stability gave way to the on-coming Coast Range mountain-making revolution of late post-Miocene time, fuller acceptance can be given their correlation of older sediments than of younger.

Their correlation of the San Joaquin sediments with the standard California section is as follows.

1. The correlation of the *Chione elsmerensis* zone of the lower Etchegoin sands with the Elsmere Canyon beds.

2. The correlation of the upper part of the Etchegoin sand and the San Joaquin clay up to and including the *Pecten coalingaensis* zone with the San Diego zone.

3. The correlation of the upper part of the San Joaquin clay, the "*Mya japonica*" zone, with the Santa Barbara zone.

4. The correlation of the Tulare formation with the Las Posas, Timms Point, and San Pedro zones.

Thus, according to their correlations, the division between Pliocene and Pleistocene would come at the San Joaquin clay-Tulare contact.

AGE AND CORRELATION OF SAN JOAQUIN CLAY

Because of its well defined stratigraphic relations, its abundant fossils, both vertebrate and invertebrate, and its well characterized thermal facies, it is believed that the San Joaquin clay will offer a unique link in world correlations. While it may be premature to attempt an age determination of the San Joaquin clay at this time, it is not amiss to derive tentative correlations from the many available lines of evidence. Despite the fact that there is a great danger in misinterpreting the evidence at hand, these correlations are offered with the belief that they are more justifiable than many of the assumptive correlations of the past.

Perhaps it is more than a mere coincidence that the Pliocene and Pleistocene history of the San Joaquin Valley should so closely parallel that of Southern California and of the European standard. If it is not a coincidence, then a comparison of the general features of the California and European sections should lead to the definite establishment of correlations.

COMPARISON OF SAN JOAQUIN VALLEY, SOUTHERN CALIFORNIA, AND EUROPEAN SECTIONS

Etchegoin sand.—The Etchegoin sand is divisible into two more or less distinct faunal units. The lower, or *Chione elsmerensis* zone can be correlated with certainty with the "lower" Pliocene "Elsmere" zone of southern California. The upper zone is clearly the correlative of the San Diego zone of southern California. A variety of *Pecten healeyi* Arnold is exceedingly abundant below the upper *Mulinia* zone. At all localities and in all well sections examined, this form terminates abruptly at a uniform horizon. The same condition has been noted by Grant and Gale in southern California. Concerning *Pecten healeyi*, they state:

> This species is an important horizon marker in southern California, disappearing rather suddenly with the first wave of the colder temperatures of the upper Pliocene.

W. P. Woodring[23] has proposed the name "*Healeyi*" zone (after *Pecten healeyi*) for the San Diego fauna wherever it may be found.

The Elsmere zone and the San Diego zone have been compared with the Plaisancien and Astien of the European section, respectively.

San Joaquin clay.—The cool-water conditions that appear suddenly at the base of the San Joaquin clay suggest a correlation with the Santa Barbara zone of southern California. The local extinction of many species at the top of the Etchegoin sand may be compared favorably with extinctions at the top of the San Diego zone and at the close of the Astien. The probable glaciation contemporaneous with the "D" zone of the San Joaquin clay appears comparable with the Günz glaciation in Switzerland. Thus the lower San Joaquin clay, including the "E" and "D" zones, may be referred to the Icenian stage of the upper Pliocene. The vertebrate fauna from the lower San Joaquin clay (the *Plesippus proversus* fauna) is regarded now as late Pliocene, by vertebrate paleontologists, and this is in harmony with the suggested correlation.

The warm-water "C" zone and the *Pecten coalingaensis* fauna of the San Joaquin clay are comparable with the warm-water Las Posas zone of southern California. The zone appears to be warmer than any of the late Pliocene zones of southern California or of Europe. Like the Cromer Forest bed of Europe it may be correlated with the first interglacial period. The appearance of the Pleistocene genus *Castor* and the last occurrence of the *Plesippus* horse in the *Pecten coalin-*

[23] W. P. Woodring, "Pliocene Deposits North of Simi Valley, California," *Proc. California Acad. Sci.*, 4th ser., Vol. 19 (1930), pp. 57–64.

gaensis zone make it seem desirable to place this zone in the transition between Pliocene and Pleistocene.

The cool-water "B" zone and the uppermost *Mya japonica* fauna may properly be correlated with the Mindelian or first Pleistocene glacial period. A vole, *Mimomys primus* (Willson), originally described from the Coso Mountain deposits, has been found in the "B" zone. This species is nearly identical with a form found in Europe ranging from the Norwich Crag to the High Terrace of the Thames. The canid, *Hyaenognathus pachyodon* Merriam, usually assigned to the Tulare formation, was probably secured from the "B" zone. The type of this species came from 200 feet in an asphalt mine near the town of McKittrick. The mouth of this mine is stratigraphically below a contact between typical Tulare material above and typical San Joaquin clay below. The contact is overlain by a bed of fresh-water fossils which are identical with species found in the basal Tulare of the type locality. While the geologic occurrence of the specimen underground is unknown, the mine workings are believed to be directed into older beds than appear at the mouth.

The "A" zone of the San Joaquin clay is tentatively correlated with the Mindel-Riss interglacial stage and with the San Pedro zone of southern California. The widespread unconformity at the base of the Tulare formation is evidence of earth movements of considerable intensity. A period of similar disturbance in southern California divides the Pleistocene into lower and upper parts.

For the reasons stated the San Joaquin clay is placed in the late Pliocene and early Pleistocene.

Tulare formation.—Largely on the basis of extinct species in the fresh-water molluscan fauna of the basal beds, the lower part of the formation has been assigned to the Pliocene. This has had an influence upon the problem of the age of the San Joaquin clay. Another influence has been the long-standing custom of regarding *Hyaenognathus pachyodon* as a Tulare fossil.

Now that the Tulare formation has become so well known from many cored wells, it seems surprising that past workers have not attempted to find the equivalents of the spreads and retreats of lakes Bonneville, Lahontan, Mono, and Manix in the San Joaquin Basin. Curiously, all of these lakes have left evidences of two advances and an intervening retreat. The sedimentary record of the ancient Tulare lake shows two advances and an intervening retreat. While we do not feel prepared to establish the suggested synchronisms, we are not unmindful of the possible significance of this resemblance. It would be most interesting to have deep well records from all of these lakes at hand.

The ancient early Tulare lake can be correlated with the "Second glaciation" of the Sierra Nevada and the Rissian glacial age of Switzerland. The retreat of the ancient Tulare lake in mid-Tulare time is comparable with the relatively long interglacial stage following the "Second Sierra Nevada glaciation" and the equally long Riss-Würm interglacial stage. The late spread of the ancient Tulare lake with its brief intermediate retreat is comparable with the "Third" and "Fourth" glaciation of the Sierra Nevada with the temporary retreat between them. The equivalent stages in Switzerland appear to be the early Würmian, the Achen interstadial, and the later Würmian.

Alluvium.—The Alluvium of the San Joaquin Valley shows no evidence of contemporaneous Sierran glaciation. The amount of Alluvium present in the valley appears to be adequate to have been derived from post-glacial erosion. The entire Alluvium section is therefore correlated with the post-glacial epoch.

Arguments against this age assignment that will be proposed are:

1. Certain species that become extinct at the termination of the San Diego zone remain in beds that are correlated higher stratigraphically in the San Joaquin Valley.

2. Correlations of thermal facies between the coastal belt and the San Joaquin Valley may be "180 degrees" at variance due to the apparent necessity for warmer ocean temperatures during periods of Sierra glaciation.[24]

3. The fresh-water fauna of the basal Tulare would appear to contain too many extinct species for the age assigned to the beds. For this, an alternative explanation may be offered. It is suggested that these "extinct" species were geographical variants in a long-isolated basin which were killed off by mid-Tulare desiccation. Were it not for this local extinction, they might have lived on into the Recent, as their related forms have in outside regions. The Pleistocene faunas of the Mojave area may not only be younger (comparable with the ancient late-Tulare lake), but they may also have been limited to the area east of the Sierra Nevada in their migrations.

[24] Most writers have correlated cool faunal zones of the California coastal belt with glacial stages of the Sierra Nevada. Some doubt is cast on the correctness of this policy and readers are referred to C. E. Grunsky, "A Contribution to the Climatology of the Ice Age," *Proc. California Acad. Sci.*, 4th ser., Vol. 16 (1927), pp. 53–85. It would appear consistent with observed geologic facts and climatological laws that no other explanation of Sierran glaciation need be offered than increased ocean temperatures and consequent increased precipitation on the Sierra Nevada. It is interesting to note that the Sierran snow-pack of 1931–32 was one of the heaviest in many years. At the same time, ocean temperatures along the California coast have been conspicuously higher. In fact, we are informed by G. D. Hanna that many species of fish, normally ranging as far north as San Diego or San Pedro, were found in sufficient numbers in Monterey Bay to be of importance in commercial fishery.

A tentative correlation between the San Joaquin Valley post-Miocene sediments, the post-Miocene section of southern California of Grant and Gale, and the erosion record of the Sierra Nevada is shown in Table II.

TABLE II

TENTATIVE CORRELATIONS

Age	*Southern California* (After Grant and Gale)	*San Joaquin Valley*	*Sierra Nevada* (After Grant and Gale)
RECENT	Alluvium	Alluvium	Post-glacial erosion
PLEISTOCENE	Ocean at Continental Border	Upper Tulare	Third and fourth glaciations with interstadial
	Palos Verdes zone	Mid-Tulare	Continued uplift
	Great deformation and erosion	Lower Tulare. Great deformation, erosion	Second glaciation (Valley erosion ¾ completed)
	San Pedro zone	San Joaquin clay, "A" zone	Beginning of uplift
	Timms Point zone	San Joaquin clay, "B" zone	First glaciation
	Las Posas zone	San Joaquin clay, "C" zone	
PLIOCENE	Santa Barbara zone	San Joaquin clay, "D" and "E" zones	Evidence of glaciation obliterated
	San Diego zone (*Pecten healeyi*)	Etchegoin sand (*Pecten healeyi*)	
	Elsmer Canyon beds *Chione elsmerensis* zone	Etchegoin sand. *Chione elsmerensis* zone	
MIOCENE?		Reef Ridge shale	

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 18, NO. 4 (APRIL, 1934), PP. 500-518, 10 FIGS.

OIL-PRODUCING HORIZONS OF GULF COAST IN TEXAS AND LOUISIANA[1]

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ABSTRACT

Discovery of the Conroe oil field in 1932 has brought into prominence the Cockfield as an oil-producing horizon in the Gulf Coast area. The various oil-producing horizons of the Gulf Coast are reviewed and discussed. Typical sections of several of the Gulf Coast oil fields are shown to indicate the position of the oil-producing sands. The possibility of production from deeper horizons in the Cook Mountain and Mount Selman formations is pointed out.

INTRODUCTION

Discovery of the Conroe oil field in the early part of 1932, the largest oil field so far found in the Gulf Coast region of Texas and Louisiana, producing from a sand in the Cockfield or Yegua formation, marked another milestone in Gulf Coast history. The productive area is 17,240 acres, and the potential reserves are 585 million barrels of oil. It is the first time that large commercial production has been obtained from the Cockfield or Yegua.

Discovery of the Raccoon Bend field in 1927 established for the first time important commercial production from the Jackson group.

Mention of these important developments suggests the desirability of reviewing the information about the oil-producing horizons of the Gulf Coast.

OIL-BEARING HORIZONS

The geologic section of this region is shown in Table I. The main oil-producing horizons are the following.

Miocene
- Basal Fleming (especially the Miocene-Oligocene unconformity)

Oligocene
- *Discorbis*
- *Heterostegina*
- *Marginulina*

Eocene
- Cockfield: Pettus sand in Southwest Texas; Conroe sand in East Texas

Oil is found also in many of the other formations. All of the occurrences are here reviewed.

[1] Presented before the Association at the Houston meeting, March 22, 1933. Manuscript received, December 14, 1933.

[2] Consulting geologist.

TABLE I

TEXAS-LOUISIANA GULF COAST GEOLOGIC SECTION

<table>
<tr><th>Series</th><th colspan="3">Group</th><th>Formation</th><th>Conroe District</th><th>Pettus District</th></tr>
<tr><td>Pleistocene</td><td colspan="3"></td><td>Beaumont
Lissie
Reynosa</td><td></td><td></td></tr>
<tr><td>Pliocene-Miocene</td><td colspan="3"></td><td>Fleming</td><td></td><td></td></tr>
<tr><td rowspan="3">Oligocene</td><td colspan="3">Upper</td><td>Catahoula</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td colspan="3">Middle</td><td>Discorbis
Heterostegina
Marginulina</td></tr>
<tr><td colspan="3">Lower</td><td>Frio
Vicksburg</td></tr>
<tr><td rowspan="8">Eocene</td><td colspan="3">Jackson</td><td>Whittsett[a]
McElroy
(T. Hockleyensis)
Caddell
(T. Dibollensis)</td></tr>
<tr><td rowspan="6">Claiborne</td><td rowspan="4">Upper</td><td rowspan="4">Yegua</td><td rowspan="2">Cockfield</td><td>"Upper Cockfield" gas sand</td><td>Pettus sand</td></tr>
<tr><td>Conroe sand</td><td>Tuleta or "Yegua sand" 170 feet below Pettus sand</td></tr>
<tr><td>Upper Saline Bayou</td><td colspan="2" rowspan="5"></td></tr>
<tr><td>Lower Saline Bayou</td></tr>
<tr><td rowspan="2">Lower</td><td>Cook Mountain</td><td>Milams
Crockett
Sparta</td></tr>
<tr><td>Mount Selman</td><td>Weches
Queen City
Reklaw
Cane River
(not everywhere present)
Carrizo</td></tr>
<tr><td colspan="3">Wilcox</td><td>Wilcox</td></tr>
</table>

[a] The Jackson group of formations is classified according to a recent paper by Miss Alva C. Ellisor, "Jackson Group of Formations with Notes on Frio and Vicksburg," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 11 (November, 1933), pp. 1293–1350. Following Miss Ellisor, the name Fayette is abandoned and Whitsett is substituted.

CAP-ROCK PRODUCTION

Modern oil history in the Southwest dates from the momentous discovery of Spindletop by Captain Lucas at the turn of the century (January 10, 1901). This discovery, only 90 miles from Houston, was the beginning of modern oil industry.

This first production, which ushered in a period of startling discoveries in the Southwest, and notably the Gulf Coast, was obtained from salt-dome cap rock—a secondary porous calcareous deposit on top of the salt core deposited after this core was intruded into the

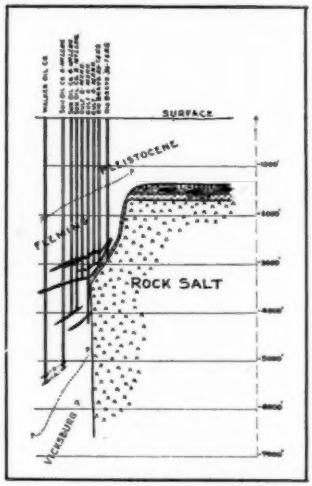

Fig. 1.—Cross section of southwest flank of Spindletop.

adjacent sediments, from bedded salt deposits at very considerable depths below the surface (possibly as much as 20,000 feet). The conditions of the occurrence of typical cap-rock production is shown in the accompanying cross section of Spindletop (Fig. 1). Similar deposits were rapidly found after the Spindletop discovery: Sour Lake in 1901, Batson in 1904, and Humble in 1905.

It is very interesting to note that the main cap-rock deposits were discovered in the period from 1901 to 1905, and that subsequently no other prolific deposits of this nature have been discovered in North America.

During this period of exploration numerous other salt domes with cap rocks within 1,000–1,500 feet of the surface were discovered by the drill, but none contained oil in any considerable quantity. Among

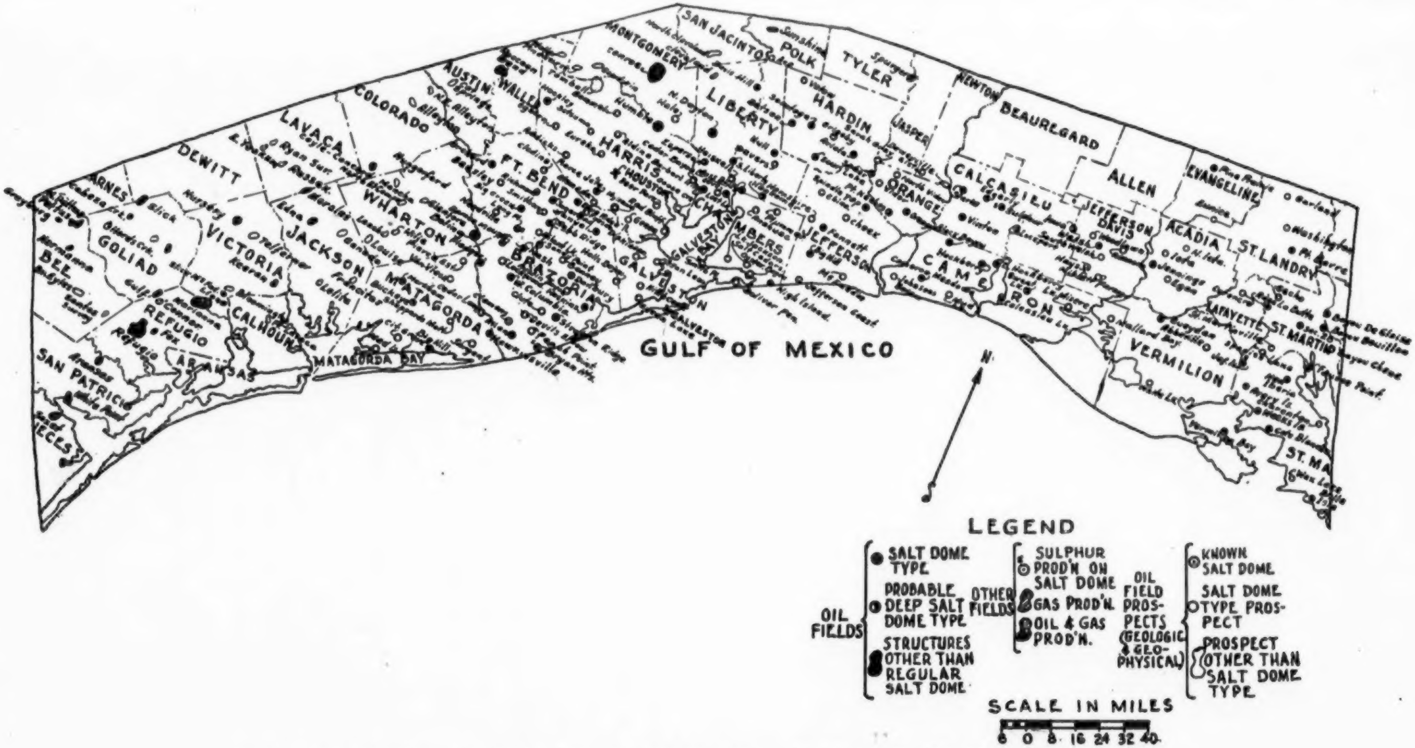

FIG. 2.—Map of Gulf Coast region in Texas and Louisiana, showing location of oil fields, salt domes, and prospects.

these domes are Piedras Pintas in Duval County; Bryan Heights, Damon Mound, Hoskins Mound, and West Columbia in Brazoria County; Pierce Junction in Harris County; Blue Ridge in Fort Bend County; High Island in Galveston County; Barbers Hill in Chambers County; North Dayton, South Liberty, and Davis Hill in Liberty County; Big Hill in Jefferson County; and Bayou Boullion, Hackberry, and Vinton in Louisiana. The location of these salt domes is shown on the accompanying map (Fig. 2).

Cap-rock production was therefore the first type of Gulf Coast production, and was predominant in the period from 1900 to 1910.

The aggregate amount of cap-rock production from the four principal domes is shown in Table II.

TABLE II

Cap-Rock Production from Four Principal Domes

Field	*Approximate Total Number of Barrels*
Spindletop	48,000,000
Sour Lake	65,000,000
Batson	31,000,000
Humble	45,000,000
Total	189,000,000

LISSIE-REYNOSA PRODUCTION

At Spindletop and Humble are several sands, varying in depth from 600 to 1,000 feet, that belong in the Lissie-Reynosa group. It is probable that the oil in these sands has accumulated by leakage from the cap rock along small fault and fracture planes. This super-cap production is small in amount. The wells range in depth from 600 to 1,000 feet, and their initial productions varied from 40 to 50 barrels. The total production per well was not in excess of 15,000 barrels. Some of these wells at Humble were long-lived, and produced during a period of 10 years or more.

MIOCENE PRODUCTION

In point of aggregate volume, Miocene production exceeded cap-rock production.

Coincident with the discovery of the major cap-rock fields in the period from 1901 to 1905, important Miocene production was discovered at Jennings in Louisiana in 1901, and at Saratoga in 1902. Both of these fields are typical salt domes, but in both of them the production is of the super-cap type, from Miocene sands above the cap-rock level. This was the first Miocene production of consequence in the Gulf Coast.

The second important milepost in Gulf Coast history was the discovery of oil in lateral or flanking sands around the edges of the salt cores in wells deeper than the cap-rock wells. Productive flank sands were discovered on the north side of Sour Lake in 1914, and on the east side of Humble in the same year. The wells ranged in depth from 2,500 to 3,500 feet—considerably deeper than the cap-rock wells.

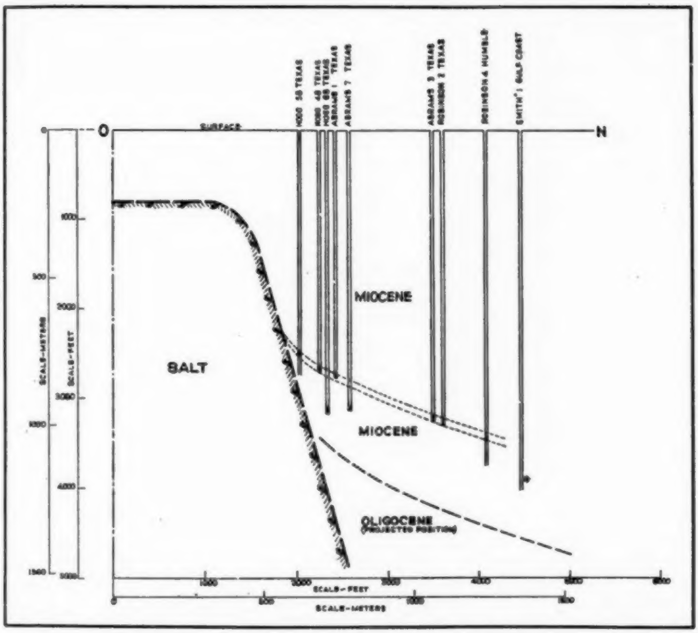

FIG. 3.—Cross section of West Columbia. After D. P. Carlton, "West Columbia Salt Dome and Oil Field, Brazoria County, Texas," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), Fig. 7, p. 458.

Though the first flank production was found on domes that had production also in the cap rock, flank production was found later in domes that had no production in the cap rock, as at West Columbia[3] (Fig. 3) and Damon Mound in 1917. These domes were tested for cap-rock production in 1901, the year of the Spindletop discovery, and were found to be dry in the cap rock.

[3] D. P. Carlton, "West Columbia Salt Dome and Oil Field, Brazoria County, Texas," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), Fig. 7, p. 458.

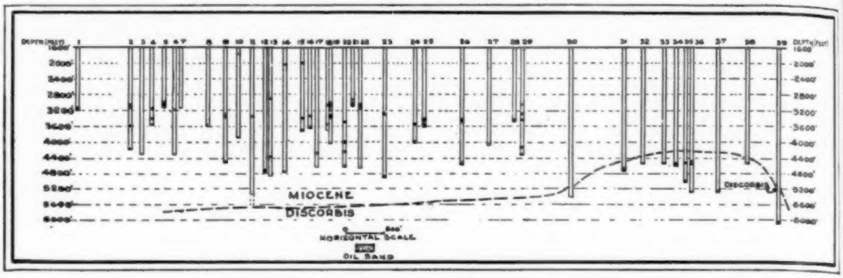

FIG. 4.—North-south cross section of Orange.

Cross Section No.	*Operator*	*Farm*	*Well No.*
1	Gulf Production Company	Kishi-Lang "A"	9
2	Gulf Production Company	Kishi-Lang	3
3	Humble Oil & Refg. Co.	K. Kishi	2
4	Gulf Production Company	Kishi-Lang "A"	4
5	Gulf Production Company	Kishi-Lang	2
6	Humble Oil & Refg. Co.	K. Kishi	1
7	Humble Oil & Refg. Co.	O. Chesson	4
8	Humble Oil & Refg. Co.	O. Chesson	27
9	Humble Oil & Refg. Co.	O. Chesson	9
10	Humble Oil & Refg. Co.	O. Chesson	1
11	Humble Oil & Refg. Co.	O. Chesson	21
12	Gulf Production Company	Chesson "A"	4
13	Continental Oil Company	O. Chesson	9
14	Continental Oil Company	O. Chesson	3
15	Orange Oil Company	O. Chesson	1
16	Gulf Production Company	O. Chesson	4
17	Orange Oil Company	O. Chesson	12
18	Orange Oil Company	O. Chesson	8
19	Gulf Production Company	O. Chesson	1
20	Gulf Production Company	O. Chesson	2
21	Humble Oil & Refg. Co.	Wm. Winfree	1
22	Humble Oil & Refg. Co.	Wm. Winfree	11
23	Humble Oil & Refg. Co.	Wm. Winfree	8
24	Humble Oil & Refg. Co.	Wm. Winfree	6
25	Gulf Production Company	Hager-Moore	3
26	Gulf Production Company	Hager-Moore	5
27	Humble Oil & Refg. Co.	M. Corbello	3
28	Supreme Oil Co.	R. Jackson	3
29	Orange Oil Company	C. Berwick	3
30	Gulf Production Company	Boyles *et al.*	3
31	Gulf Production Company	Lee Hager fee	15
32	Gulf Production Company	F. T. Peveto	8
33	Brown-Babette Oil Company	E. W. Brown Est.	1
34	Sun Oil Company	Mrs. C. L. Brown *et al.*	3
35	Rycade Oil Corp.	State "E"	1
36	Sun Oil Company	Mrs. C. L. Brown *et al.*	2
37	Rycade Oil Corp.	State "E"	14
38	Rycade Oil Corp.	State "E"	15
39	Sun Oil Company	Mrs. C. L. Brown *et al.*	6

At Goose Creek[4] and at Orange (Fig. 4) no typical salt-dome structure is present, and the oil is found in a series of sands slightly arched, mostly Miocene in age.

It is now considered that both Goose Creek and Orange are deeply buried salt domes, and that this production is of the super-cap type.

Oil at Goose Creek was discovered in 1908 and at Orange in 1913. It was not until a 3,000-foot well was drilled at Goose Creek in 1916 that prolific production was established, in sands of Miocene age.

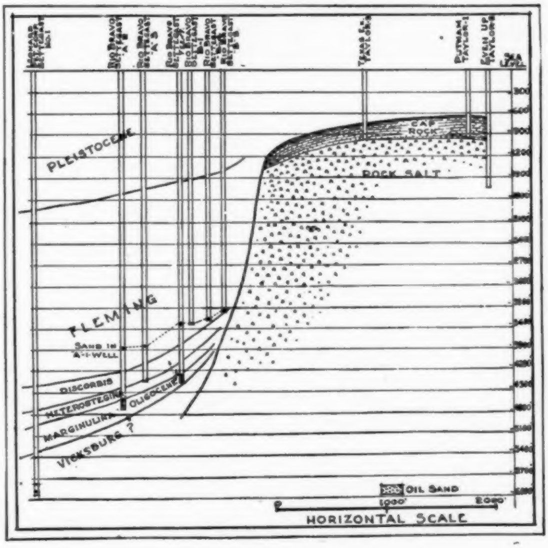

FIG. 5.—Cross section of west flank of Pierce Junction, showing position of oil-producing horizons.

In those fields where important production has been found in flank sands, much of this oil occurs at the unconformity between the Miocene and the Oligocene. This is the case at Pierce Junction (Fig. 5) and at West Columbia (Fig. 3).

Table III summarizes the outstanding Miocene producers.

The total Miocene production to date is approximately 320 million barrels of oil, as compared with 189 million barrels of cap-rock production.

[4] H. E. Minor, "Goose Creek Oil Field, Harris County, Texas," *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), Fig. 4, p. 553.

TABLE III

MIOCENE PRODUCTION FROM PRINCIPAL DOMES

Fields	*Approximate Total Number of Barrels*
Flank Production	
Spindletop	50,000,000
West Columbia	74,393,000
Pierce Junction	15,000,000±
East Hackberry	2,000,000±
Super-Cap Production	
Jennings	41,000,000
Saratoga	26,000,000
Deep-Seated Domes	
Goose Creek	69,000,000
Esperson	2,000,000
Lockport	10,000,000±
Orange	30,000,000
Total	320,000,000

In addition to the foregoing, production is obtained from the Miocene in the following fields, but exact amounts can not be indicated at this time.

1. Port Neches, in Orange County, has 5 wells 3,100–4,400 feet deep, completed in the lower Miocene.

2. The important Thompsons field, in Fort Bend County (discovered in 1931), has 4 wells, ranging in depth from 3,000 to 3,500 feet, producing from the Miocene.

3. Manvel, in Brazoria County, has 3 wells producing from the lower Miocene (Oakville) at a depth of 4,000 feet. The Manvel horizon is the same as the one producing at Port Neches, but is lower in the section than the 3,500-foot sand at Thompsons. The 4,000-foot Miocene sand at Thompsons is approximately the equivalent of the Manvel sand.

OLIGOCENE PRODUCTION

Oligocene production was established with the drilling of the flank sands around the salt domes in the second epoch of Gulf Coast history, beginning with 1914, when 3,000-foot wells began to be drilled.

The main producing formation of the Oligocene is the *Heterostegina*, although production is likewise obtained in the *Discorbis*, and within the past 2 years the *Marginulina* has become an important producing horizon.

The production from the major fields producing from Oligocene formations is set forth in Table IV.

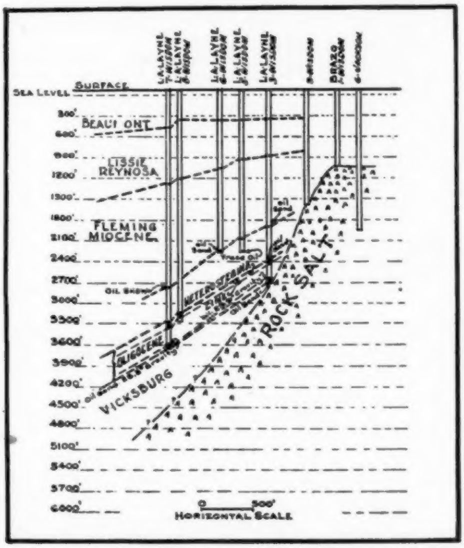

FIG. 6.—Cross section of north flank of Damon Mound.

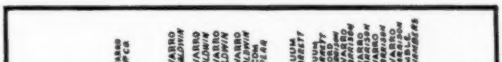

FIG. 7.—Cross section of east flank of South Liberty dome.

TABLE IV

OLIGOCENE PRODUCTION FROM PRINCIPAL FIELDS

Field	*Approximate Total Number of Barrels*
Humble	
Flank	60,000,000±
Damon Mound	9,000,000±
Hull	
(Includes some Miocene—total Hull production 70,000,000 barrels)	30,000,000±
South Liberty	30,000,000±
Barbers Hill	
(Some production from Miocene; likewise from the *Discorbis* and *Marginulina* zones)	22,000,000
Sugarland	13,000,000
Vinton	36,000,000
Total	200,000,000

Cross sections showing the conditions at Damon Mound, South Liberty, and Sugarland, are shown in Figures 6–8.[5]

In addition to the fields listed in Table IV, production from the Oligocene is obtained in the following fields.

1. The deep sand on the Spindletop flank below 5,000 feet is Oligocene in age, and yields substantial production (Fig. 1).

2. At West Columbia is a sand producing from the Oligocene lying below the *Heterostegina* limestone. The yield from this sand has been small as compared with prolific Miocene sands (Fig. 3).

3. On the west side of Pierce Junction production from the *Marginulina* formation of the Oligocene is obtained on the Rio Bravo lease (Fig. 5).

4. At Goose Creek the oil-bearing sands below 4,500 feet are Oligocene in age.

5. Flank production on the south side of East Hackberry in Louisiana is from the Oligocene.

6. The deep sand on the western edge of the Lockport field near Lake Charles, Louisiana, approximately 6,000 feet in depth, is Oligocene in age.

7. On the south side of Orange field, where the *Discorbis* formation is uplifted to its maximum elevation, some production is obtained from this formation below 4,800 feet in depth (Fig. 4).

8. Some of the flank sands at Blue Ridge, Fort Bend County, are Oligocene in age.

9. In the newly discovered Iowa field in Calcasieu Parish, Louisiana, important production is obtained from the Oligocene in wells approximately 6,900 feet in depth.

[5] For a cross section of Barbers Hill, see Sidney A. Judson and R. A. Stamey, "Overhanging Salt on Domes of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 12 (December, 1933), Fig. 10, p. 1515.

10. At Lost Lake, Chambers County, a small amount of oil has been obtained from the Oligocene, but this production to date is not of commercial importance.

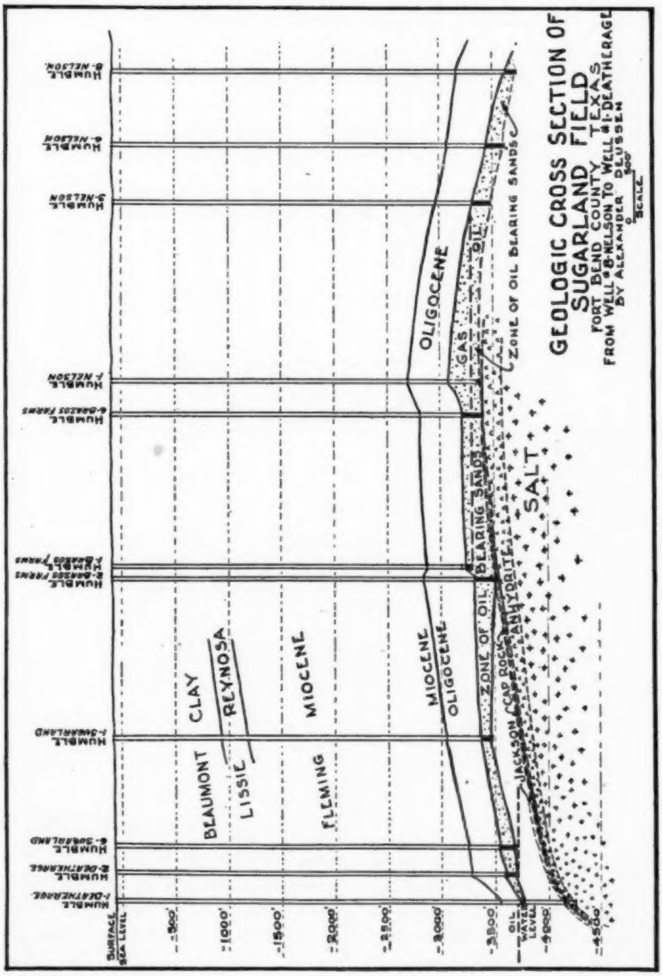

FIG. 8.—Northwest-southeast cross section of Sugarland dome.

11. In the Mykawa field, Harris County, some of the wells are producing from the Oligocene, but this production is not of great importance (Fig. 9).

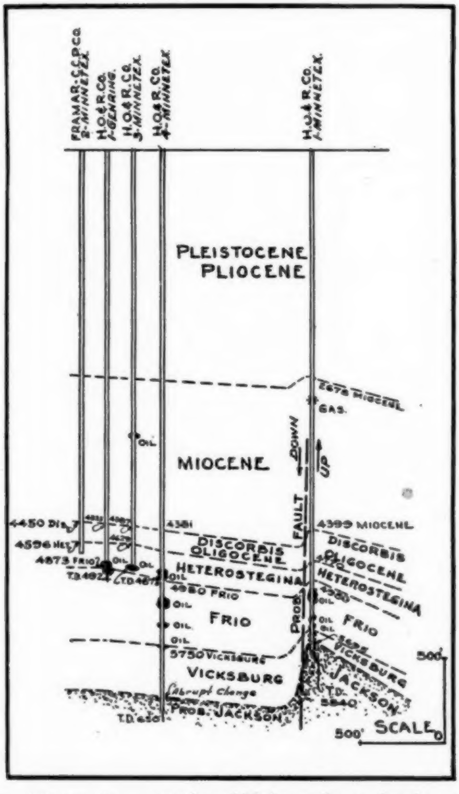

Fig. 9.—West-east cross section of Mykawa dome, showing position of oil-producing sands. (After Cashin.)

12. The Thompsons field in Fort Bend County—a deep dome field—is, next to Conroe, the most important field of the Gulf Coast. To date (September 1, 1933) this field has produced only 8,470,978 barrels of oil, but the ultimate reserves are estimated at 166,000,000 barrels. As previously indicated, 4 wells in this field are producing from the Miocene. There is no production from the *Discorbis* or the *Heterostegina* formations, but 16 wells are producing from the basal *Marginulina*, at a depth of approximately 4,850 feet. Twenty wells

are producing from the *Marginulina*, and a formation below the *Marginulina*, which on the basis of fossils is referred to the Frio (?). These 20 wells range in depth from 4,850 to 5,300 feet.

13. At Manvel one well is producing from the *Marginulina* at 5,200 feet.

14. At Pledger, Brazoria County, a new prospect, discovered in 1932, is a sand in the basal *Marginulina* at 6,782 feet, producing gas.

15. Stoddard or Buckeye field, Matagorda County, was discovered in 1932, and at the present time is the deepest producing field of the Gulf Coast. Production is obtained from the basal *Marginulina* at 7,925 feet. This horizon may be lower in the section than the *Marginulina* production at Thompsons. The Oligocene section in the Buckeye field is substantially thicker than at Thompsons.

It is to be noted that *Marginulina* production has become of major importance in the last two or three years. The first *Marginulina* oil was discovered at Pierce Junction in the year 1925, and this was followed by the discovery of *Marginulina* production at Thompsons in 1931, and at Buckeye and Pledger in 1932. The basal *Marginulina* horizon promises to be a very important producing formation throughout the areas of Harris, Fort Bend, Brazoria, and Matagorda counties. It has come into prominence as an oil producer only since wells have attained a depth of 5,000–6,000 feet.

LOWER OLIGOCENE PRODUCTION

Lower Oligocene production is from the Frio and the underlying Vicksburg formation. With the exception of the wells that are producing from sands assigned to the Frio in the Thompsons field, production from these horizons is not of very great importance. At Mykawa some sands in the Frio contain oil, but no wells of great value have been completed (Fig. 9). The sands in some of the deep wells (6,500 feet) at Barbers Hill are referred to the Vicksburg. The wells producing from these sands are not the best wells in this field.

JACKSON PRODUCTION

Production from the Jackson was first established with the drilling of the lateral sands at Humble in 1914.

The so-called "black shale," which is Jackson in age, and underlies the Oligocene producing sands on the east flank at Humble, contains oil of light gravity, varying from 45°–55° Bé., and of entirely different character from that found in the Oligocene sands, containing considerably larger proportions of gasoline and kerosene than the normal so-called "Grade A" oil of the Humble deep sands. The gravity of the latter varies from 22° to 24° Bé.

Later, similar wells were completed in the identical formation at Vinton, South Liberty, and Hull, but the production from this "black shale" has been small in volume.

The discovery of the Racoon Bend field in Austin County by the Humble Oil and Refining Company in 1927 was very important in three respects.

1. Prior to this discovery, Gulf Coast operators considered there was little or no chance for finding production in the belt of country north of Humble field. Up to that time no shallow or deep domes were known to occur in this north belt, excepting, of course, the interior salt domes of Anderson, Smith, Freestone, and Cherokee counties in East Texas, which with the exception of Boggy Creek in Anderson and Cherokee counties, had not produced oil in commercial quantities. Raccoon Bend lies considerably north of the old salt-dome belt, and is in the outcrop of the Reynosa, a short distance south of the outcrop of the Lagarto or Fleming clay. Attention was now forcibly called to the possibilities of this north belt of country, or so-called "Raccoon Bend trend," and a very active campaign of development followed, leading to the discovery, in 1930, of the Pettus field in Bee County.

2. Raccoon Bend focused attention on the possibilities of the so-called "deep domes" or "deep structures." Previous to this time the familiar Spindletop type of salt dome was still primarily the object of search. Thereafter, the Gulf Coast operator began actively to look for the deep structures—deeply buried salt cores (salt top at 10,000 feet or more), with arching or doming in the overlying beds—the Goose Creek or Orange type of salt dome. This campaign eventually resulted in the discovery of Conroe, and at the present time exploratory activity in the Gulf Coast is directed mainly toward discovering additional structures of this type.

3. At Raccoon Bend there was obtained for the first time production from the Jackson of a type different entirely from that obtained in the "black shale" in the shallow or piercement-type domes. The Raccoon Bend production is obtained from the Whitsett and McElroy formations of the Jackson. The so-called "Gutoskey sand" is found at a depth of 3,100–3,250 feet, 40 feet above the contact of the Whitsett and the McElroy. The lower, or so-called "Grawunder sand," is found at a depth of 3,420–3,570 feet, 320 feet below the "Gutoskey sand," 280 feet below the top, and in about the mid-portion of the McElroy.[6]

[6] At Raccoon Bend the uppermost producing sand is a gas sand, yielding considerable quantities of gas. It is found at a depth of 950–1,050 feet, at the top of the Oakville (lower portion of Fleming) formation.

This was the first time that production was obtained from the Whitsett and McElroy in the Gulf Coast. Total production from this field, to January 1, 1933, is approximately 10,443,165 barrels.

YEGUA PRODUCTION

Beginning with 1929, the third important epoch of Gulf Coast history, 5,000-foot wells became common. In previous years, of course, a few wildcat wells had been drilled as deep as this, but until 1929 no production in substantial amount had been secured.

In 1929 H. R. Cullen went beyond the limits of proved production on the southeast side of Humble, and completed a well below the "black shale," producing from the Upper and Lower Saline Bayou formations of the Yegua, at a depth of 5,347 feet. This was the first time that production in substantial amount was obtained from this formation. The "black shale," or "heaving shale," is very difficult to penetrate, and up to the time of Cullen's success, wells were commonly abandoned when it was encountered.

In 1930 oil was also found in the Yegua formation in the Pettus field of Bee County. In this discussion the Pettus sand is considered to be in the upper portion of the Cockfield formation, and equivalent to the "Upper Cockfield gas sand" in the Conroe field. Some paleontologists place the Pettus sand at the base of the Jackson and not in the Yegua.

At present the Yegua is the most important producing formation of the Gulf Coast, and it seems that production from it will considerably surpass the production of any of the younger formations, which prior to 1930 were the main producers. The reason for this preëminence is the fact that it is the producing horizon of the Conroe field, the largest and most important oil field thus far discovered in the Gulf Coast.

Conroe, found early in 1932 on the Raccoon Bend trend (now called the Conroe trend), has two producing sands, both in the Cockfield formation (Fig. 10). The so-called "Upper Cockfield sand," 30 feet below the top of the Cockfield, is 20–25 feet in thickness. It contains gas in the central portion of the field. On the east and south flanks it contains oil.[7]

The main sand is the "Conroe," about 200 feet below the top of the "Upper Cockfield sand," and 230 feet below the top of the Cockfield formation. The thickness is about 275 feet. Above the −4,850

[7] Above the "Upper Cockfield gas sand" are six other gas sands. The top sand is at 1,000–1,200 feet in the Oakville. The remaining five are in the Lower Oakville, Catahoula, and Frio formations.

foot contour it contains gas. The original water level for the Conroe sand was −4,990 feet. The wells are approximately 5,100 feet in depth.

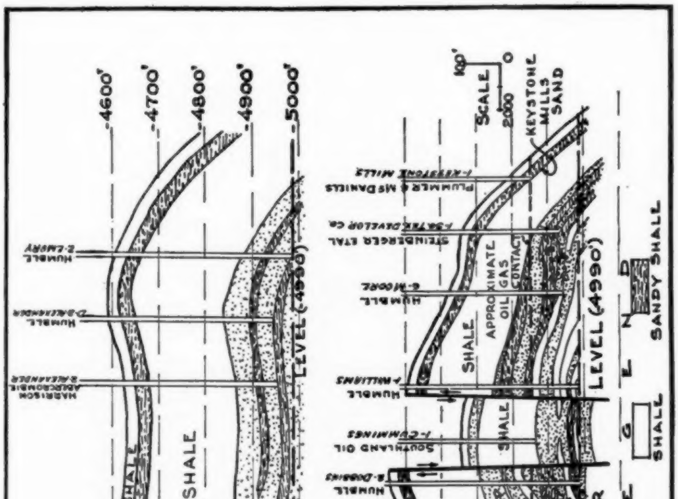

FIG. 10.—Cross sections of Conroe field. (After Michaux.)

UPPER AND LOWER SALINE BAYOU PRODUCTION

Attention has been called to the fact that the deep production discovered at Humble in 1930 came from the Upper and Lower Saline Bayou of the Yegua, formations below the Cockfield, being the lower Yegua.

Some of the deep production at Hull is obtained from the Upper Saline Bayou formation.[8]

COOK MOUNTAIN PRODUCTION

On the northwest side of the Humble dome some production of no great importance has been found in the Cook Mountain (?) formation.

On the Clay Creek dome, Washington County, production is obtained from the Sparta member at the base of the Cook Mountain.[9]

In Nacogdoches County some shallow wells, 100–300 feet in depth have produced a few barrels of oil from the Cook Mountain.[10]

The Cook Mountain formation has not been a prolific producer.

MOUNT SELMAN PRODUCTION

Some of the shallow sands in Nacogdoches County, and some in Angelina County, belong to the Mount Selman formation. On the Clay Creek dome some production is obtained from the Queen City and Carrizo sands. The Carrizo is considered here as the base of the Mount Selman. Like the Cook Mountain formation, the Mount Selman has not produced much oil; however, if history should be repeated, the possibilities of these two formations are not to be ignored. It may be that future development will bring into prominence another belt of country, north of the Conroe trend, or that 7,000–10,000-foot wells on structures on the Conroe trend, or in the old salt-dome belt, will result in productive fields surpassing any now known.

In looking backward this writer recalls that no Coastal Plain geologist would concede the possibility of production in the Woodbine sand in Texas, until the Mexia field was discovered in 1920. The same statement applies as to production from Edwards limestone, prior to the discovery of Luling in 1922.

Prior to the discovery of Raccoon Bend, few, if any, Gulf Coast geologists would concede it was possible to produce oil north of the

[8] Production at Hull is obtained from several sands, ranging in age from Miocene to Upper Saline Bayou (Eocene).

[9] For cross section of Clay Creek, see F. E. Heath, J. A. Waters, and W. B. Ferguson, "Clay Creek Salt Dome, Washington County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 1 (January, 1931), Fig. 4, p. 51.

[10] The first attempt to develop oil production in Texas was made in Nacogdoches County in 1867. Efforts continued until 1890. Small production was developed with primitive equipment in shallow Cook Mountain sands.

old salt-dome belt, and on the Raccoon Bend or Conroe trend. Conroe was the second largest field in Texas before many of the Gulf Coast geologists realized it.

SUMMARY—GULF COAST OIL PRODUCTION

Horizons	*Barrels*
Cap rock—first period of oil exploration; youngest of Gulf Coast producing formations; wells 1,000–1,200 feet in depth; from 1901 to 1914 produced approximately	189,000,000
Miocene—later period, 1929; from 1914 to 1929; wells 3,000 feet deep produced approximately	320,000,000
Oligocene—about the same time; wells of nearly same depth yielded approximately 200,000,000 barrels, but to this should be added indicated reserves of *Marginulina*, or lower portion of Oligocene, brought into prominence with the discovery of Thompsons in 1931; wells 5,000 feet in depth, 250,000,000 barrels. Total	450,000,000
Yegua—Conroe and Pettus sands; later period, beginning 1929, when 5,000-foot wells became common. Now in sight approximately	600,000,000

During the passage of 33 eventful years, older formations and deeper wells have successively and progressively contributed substantially larger quantities of oil. This writer ventures to predict that history will be repeated, in regard to production from the Cook Mountain and Mount Selman formation.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 18, NO. 4 (APRIL, 1934), PP. 519-530, 4 FIGS.

McFADDIN-O'CONNER, GRETA, FOX, REFUGIO, WHITE POINT, AND SAXET FIELDS, TEXAS[1]

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Corpus Christi, Texas

ABSTRACT

The McFaddin-O'Conner, Greta, Fox, Refugio, White Point, and Saxet fields are approximately along the same strike, and field-to-field correlations are satisfactorily established.

In the Refugio and White Point fields most of the drilling was done before adequate coring methods and proper sample collection and examination facilities were established; hence, graphic log correlations, in themselves alone not very satisfactory, must be relied upon largely for structural pictures.

In the McFaddin-O'Conner, Greta, and Fox fields, drilling has not progressed to the point where complete structural pictures can be delineated, but intelligent coring, sample collection, and sample examination, have assisted in giving reasonably accurate subsurface data.

An accurate and fairly complete subsurface map may be drawn of the Saxet field.

It is believed that all of these fields are structural. The shapes of the producing areas, where they have been sufficiently outlined, have suggested that they are deep salt domes, although salt has not been found in any of them. Faulting of considerable magnitude is known to exist in connection with them.

Numerous producing sands appear in each field. Gas and oil production comes from both the Oligocene and Miocene beds, and, as a general rule, the gravity of the oil produced increases with depth.

The most reliable correlation markers are the *Heterostegina* and *Discorbis* zones, which have been considered Oligocene in age. Another marine zone, of doubtful value, and probably Miocene in age, is known to exist about 200 feet above the *Discorbis* zone.

Emphasis is placed upon the value of adequate coring in these fields. The difficulty of making reliable graphic log correlations of wells in the area which have not been properly cored is apparent to anyone attempting serious correlation work here.

INTRODUCTION

Acknowledgments.—Grateful acknowledgment is made to the Gulf Production Company for its permission to present this discussion, and to the United Gas System, the Humble Oil and Refining Company, The Texas Company, and individuals who have joined with representatives of these companies in furnishing much needed information and criticisms in its preparation.

Purpose.—It is the purpose of this paper to show the facts in the area treated, and to draw a few deductions from those facts. No at-

[1] Read before the San Antonio Section of the Association at the Corpus Christi meeting, November 28, 1933. Manuscript received, January 1, 1934. No paleontologic identifications mentioned in this paper were made by the writer. Such information was obtained from reports of several paleontologists of South Texas.

[2] Geologist, Gulf Production Company.

tempt is made to discuss any of the numerous arguments extant concerning the age or the nomenclature of the formations treated herein.

Location.—The fields with which this paper deals are the McFaddin-O'Conner, in Victoria and Refugio counties, the Greta, Fox, and Refugio fields, in Refugio County, the White Point field (the oldest of all), in San Patricio County, and the Saxet field, in Nueces County. Figure 1 is a general map, showing the names and locations of these productive areas.

HISTORY OF DEVELOPMENT

White Point field.—In the order of discovery, the field at White Point, San Patricio County, is first to be discussed. Concerning the early history of this field, W. Armstrong Price states:

> Hydrogen sulphide gas, seeping from a spring or water hole at the west side of the White Point peninsula, led to the exploration for oil, according to the theory that a salt dome might be present.
>
> Disseminated grains of sulphur are found in sandy sediments on the west side of the peninsula. Subsequent drilling of sixty-six wells has not disclosed salt dome . . . materials.
>
> The first well in the field was drilled about 1907 by Randolph Robertson, and blew gas for several days from its total depth of 400 or 450 feet. Shortly afterward, Lee Hager and others drilled to 1,200 feet, and also found gas.[3]

The first commercial gas well was the White Point No. 3, drilled by the Gulf Production Company in 1916. Since that time, many gas wells have been drilled here, and two oil wells, the first coming into production in November, 1930. As of September 30, 1933, these two wells had produced 47,133 barrels of oil. The oil comes from a sand found in the two wells in question at about 4,800 feet (Fig. 2). Most of the wells in the field were drilled to shallow depths, with an idea of finding gas, and the deep oil possibilities have not been thoroughly tested.

Refugio field.—The next field to be discovered was Refugio. It is reported that the first well to be drilled there was so located because of a sandstone outcrop in Mission River in the vicinity. This well was drilled in 1917, and showed several gas sands, but it was not until 1920 that the first commercial gas well was completed. Although considerable drilling followed, oil was not discovered here until 1928, when it was found in the Clint Heard No. 1, drilled by the Texas Gas Company. The field has produced over 27 million barrels of oil, from more than 250 wells. Over half of this production has come from the so-

[3] W. Armstrong Price, "Discovery of Oil in White Point Gas Field, San Patricio County, Texas, and History of Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (1931), pp. 205–10.

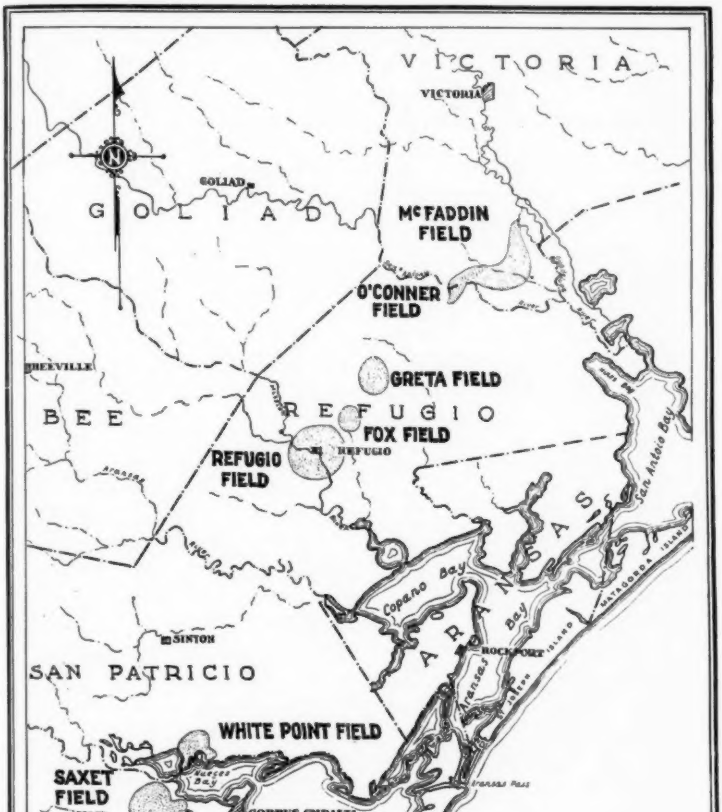

FIG. 1.—Map showing names and locations of some oil and gas fields of lower Texas Coastal region. Shaded portions represent approximate outlines of productive areas.

called "3,800-foot" sand. Other productive oil sands have been found between the depths of 5,300 and 6,400 feet, the latter sand being the deepest productive sand yet known (Fig. 2). The gravity of the oil from the "3,800-foot" sand ranges from 22° to 25° Bé. Oil from the deeper sands ranges from about 36° Bé. to gasoline.

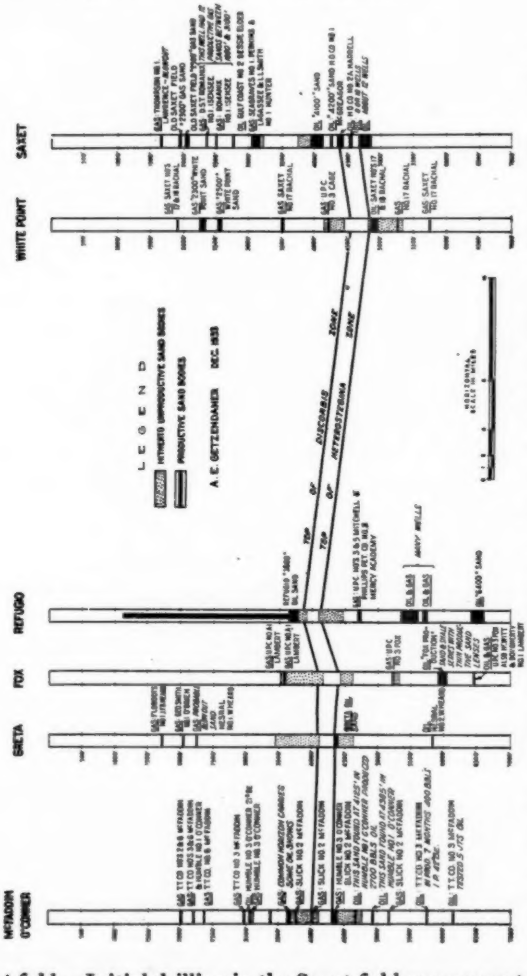

FIG. 2.—Generalized cross section composed of type log of each field. Productive sands and other important sand bodies are shown, with most important paleontological markers.

Saxet field.—Initial drilling in the Saxet field was prompted by the area's location along the strike south of, and in proximity to, the pro-

ductive White Point field across Nueces Bay. The first well to show gas was the Pioneer's Meaney No. 1, drilled about 1922. The first well completed as a commercial gas producer was drilled in 1923. This was the Saxet Company's Dunn No. 1. The first oil well in the field, the Saxet Company's Dunn No. 6, was completed in 1930. Twenty oil wells had produced 1,272,033 barrels of oil, on September 30, 1933. As shown on the cross section (Fig. 2), oil has been found in several sands.

Fox field.—The first well in the Fox field was the No. B-1 of the same name, drilled by the United Gas System, and completed as an oil well on August 8, 1931. Leases in this field are controlled by that company. An area of surface sand, thought to be Lissie in age, and therefore structurally high, led to the first development. On September 30, 1933, the seven wells in this field had produced 1,391,278 barrels of oil. Oil production to date has been almost entirely restricted to the so-called "5,800-foot" sand (Fig. 2).

McFaddin-O'Conner field.—The next field in order of discovery is the McFaddin-O'Conner, where the Lion Oil and Refining Company's McFaddin No. 1 was located by Ike Howeth, and finished as a gas well in June, 1930, on what he considered a Lissie sand inlier within the Beaumont Plain. Appearance of gas in water wells in the area emphasized the apparent structural value of this prospect.

As shown on the cross section, many gas sands and several oil sands have been found, the latter ranging in depth from about 3,000 to 6,200 feet. Mechanical and other difficulties, however, have contributed in obscuring the true potentialities of these sands. As in the other fields considered in this paper, the gravity of the oil produced increases with depth.

Greta field.—The discovery well of the newest of these fields, at Greta, northeast of Refugio, was completed in May, 1933. This well, George E. Smith's O'Brien No. 1, came in as a good oil producer. Numerous small drilling blocks, and the rising price of oil, contributed in promoting rapid and aggressive drilling, and on September 30, 1933, the field had produced over 500,000 barrels of oil from more than 25 wells. Proration has materially cut down the potential total production to date. On the cross section (Fig. 2) only two oil sands are shown as having been productive. The most important of these sands is the so-called "Greta pay," found at about 4,400 feet. Oil has also been produced from the "5,800-foot," or "Fox" sand, discovered in the Nesral Oil Company's Wilson Heard No. 2 well. Upper gas sands have also been found (Fig. 2).

DISCUSSION OF GENERALIZED CROSS SECTION

Figure 2 is a generalized cross section, composed of a type log taken from each field treated in this discussion. Emphasis is placed upon the fact that in the preparation of a type log of a field, particularly if that field shows production through several hundred feet of dip, and a lenticular development of sands and shales within a known productive zone (especially if that zone is several hundred feet in thickness), some distortion of the true position of the sands in the type section must naturally ensue. For example, it was found necessary to show, in the Saxet field type log, the well known "2,300-foot" sand just below 1,900 feet. It should be borne in mind, however, that the sands and markers are shown in this cross section in approximately correct stratigraphic position.

It will be noted that some of the productive sands are shown with a thickness of several hundred feet. This does not necessarily mean that any well shows such a thickness of actually productive sand. In these fields, production usually comes from a series of sand and shale lenses, which Maxwell[4] has demonstrated can show a remarkable gravitational arrangement of oil, gas, and salt water. Either oil or gas, or both, are separated from water, either above or below, by a shale break only a few inches in thickness. In other words, any portion, not necessarily all, of the thick sand bodies shown in the cross section as being productive, may produce in one well, and not in its nearest offset.

It will be noted that no specific sand body is indicated in the Refugio field, above the so-called "3,800-foot" sand. Many productive sands are found in this upper section, but logs, coring records, and well histories are so poor, and lensing of sand and shale bodies so pronounced, that it seems inadvisable to attempt to show them individually. Fred Shayes, of the United Gas System, who has studied this problem, states that no less than 25 productive sands exist here between the depths of 1,100 and 3,800 feet.

The paleontological markers of greatest value in these fields are the *Heterostegina* and *Discorbis* zones, which have been considered Oligocene in age. The *Marginulina* zone, below the *Heterostegina*, and of considerable value in correlation elsewhere in the Gulf Coastal region, does not appear to be sufficiently well developed in this area to be very useful.

The tops of the *Heterostegina* and *Discorbis* zones are shown on the

[4] R. G. Maxwell, "Exceptional Association of Oil and Water in Producing Zones at Refugio, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (1931), pp. 953–64.

cross section (Fig. 2). Attention should be called to the thick sand bodies also shown, one of which is found just below the first normally reported appearance of *Heterostegina*, and the other just above the horizon at which *Discorbis* commonly appears.

Another fossiliferous marine zone, which serves as a marker, is present within the upper sand body, about 200 feet above the top of the *Discorbis* zone. This zone bears no definite diagnostic fauna, but may contain ostrocods, *Elphidium*, *Lenticulina*, and oyster shell fragments. This zone is most probably Miocene in age.

A considerable distance, at places 2,000 feet or more, below the top of the *Heterostegina* zone, there is still another marine marker of more or less value. In many places it contains *Textularia warreni*, considered by some to be its index fossil. Some paleontologists have considered the fauna of this zone to be Vicksburg in age. This so-called Vicksburg has been noted in a few of the deep wells drilled within the area treated in this paper, and allusions to its indications as to structure are made later in this discussion. This zone is not shown on the cross section.

Some reference has been made to the possible ages of the beds considered herein. Their precise ages, however, must be decided by paleontologists. It is merely emphasized that the markers here mentioned are known, can be recognized, and must be used before effective correlations can be made. Further reference is made to the inadequacy of purely lithologic correlations based on well logs.

STRUCTURE

White Point.—In the White Point field, though there are many wells, the logs are poor, deep wells are few, and the paleontologic information is inadequate. The geologist is therefore forced to rely largely on graphic well-log correlations in his preparation of a structural map. Such correlations suggest a pair of small domes, each with western closure.

Refugio.—Scanty paleontologic information, combined with comparisons of the ordinarily very poor well logs, indicates that on the "6,400-foot" and shallower sands no abnormalities inconsistent with dome-shaped structure are suggested. The word "suggested" is emphasized. Definite evidence as to the exact nature of the structure is deplorably lacking.

A few observations, however, may be made in connection with the correlations in the upper part of the section. Each productive sand, particularly the "3,800-foot" sand (Fig. 2), has an arc-shaped productive area around a central and appreciably higher portion. This

"high" is well shown by the United Production Corporation's Fannie Heard No. 11, which is known to be several hundred feet higher structurally than the productive edges of the field. *Discorbis*, *Haphlophragmoides*, *Globigerina*, and *Nonionella* are found in a sample taken from this well at 3,689 feet, and a sample taken from 3,981 feet contains *Heterostegina*.

Regarding deeper formations in this field, only three wells have been drilled to interesting depths below the "6,400-foot" sand, from which useful information is available. In the consideration of these wells, it is, as usual, necessary to rely largely upon paleontology, since correlations of well logs are most disappointing. Poorly kept samples and information on one of these wells necessitates its use for contributory information only. This well is the Mission Drilling Company's Moss Heard No. 1, in the north-central portion of the field. The only definite correlation obtained from this well is that, at 7,968 feet, it was in a fossiliferous horizon carrying *Ammobaculites*, *Nonion*, and numerous pelecypod shells. No definite top of any marine zone is known.

South of the Moss Heard well, but still in the north-central portion of the field, the Independent Oil and Gas Company drilled Jerry Reilly No. 6 to a depth of 7,618 feet. The statement may be made, based on good samples and suites of fossils, that the so-called Vicksburg, carrying *Textularia warreni*, *Cristellaria* sp., *Textularia mississippiensis*, *Ammobaculites*, and *Siphonina* sp., was penetrated at a depth of about 7,553 feet, and that those fossils persist to the well's total depth.

The deepest well in the field, or in the entire area, is Edwin M. Jones' Mitchell No. B-1, located on the southeastern edge of the field. In view of the observations to follow, it should be emphasized that all three of the deep wells now under discussion found the shallower sands and the "6,400-foot" sand (Fig. 2) at about the depth where they normally would have been expected, on the structure. In the case of the B-1 Mitchell well, however, in four complete paleontologic reports to which the writer had access, neither *Textularia warreni*, nor any of its normal associates, was noted above about 8,500 feet, or 950 feet lower than in the Reilly well described in the preceding paragraph. Above that depth, to the "6,400-foot" sand, little evidence of marine life is found, and what is found consists only of an occasional ostrocod, pelecypod shell fragment, or some other non-diagnostic form.

It may be contended by some that a comparison of this portion of the section in the Jerry Reilly No. 6 and in the Mitchell B-1, merely

indicates a marine phase below the "6,400-foot" sand in the one well, and a largely non-marine phase of the same section in the other. To the writer, however, such a change, affecting so radically almost 1,000 feet of section in a distance of a little over a mile, strongly suggests a large fault, which occurred after the deposition of the *Textularia warreni* zone and before that of the "6,400-foot" sand. Such a suggestion appears particularly plausible in view of what is said later concerning the structural features of the McFaddin-O'Conner and Saxet fields.

Saxet.—In contouring the Saxet field, many geologists have been forced to limit themselves almost exclusively to the use of graphic well-log correlations. A reasonably satisfactory map may be prepared by such a method. It happens, however, that when paleontology is used in connection with the graphic correlations, startlingly new and unsuspected features appear. Due to the splendid assistance of the United Gas System and others, in furnishing paleontologic information for the preparation of this paper, the writer has been enabled to prepare what is believed to be a fairly accurate explanation of structural conditions in the Saxet field.

The old (eastern) portion of the Saxet field (Fig. 1) is contoured as a gradually eastward dipping nose. Graphic correlations are reasonably satisfactory here, since, as a general rule, the "2,300-foot" or "2,500-foot" gas sands (Fig. 2) were the objectives of the older wells, and were found and properly logged. The most western wells in this eastern division are the Saxet Company's Walton No. 2, and the Sun Oil Company's Donnegan No. 2. Wells furnishing good paleontologic information in this division are, for example, the Saxet Company's Dunn No. 6, and Donnegan No. 2. The top of the *Discorbis* zone is found in productive wells in this portion of the field as low as 4,900 feet, and the top of the *Heterostegina* zone as low as 5,200 feet.

The western and most recently developed portion of the field has, as its most eastern well, the Houston Oil Company's Ran Morgan No. 2. The structure of this part of the field is dome-like with a slight western closure. The interesting fact is, however, that the *Discorbis* zone is found here as high as 4,450 feet, and the *Heterostegina* zone as high as 4,700 feet. Good type logs in this portion of the field, with excellent fossils to accompany them, are those of the Gulf Coast Oil Company's Bessie Elder No. 1, and the Perkins and LaGasse No. 1, drilled by Titus and Calloway.

An area about 3,000 feet wide, in which no wells have been drilled as yet, separates the old and new portions of the field. It is obvious, though, from the facts already given, that a displacement, down toward the east, of more than 300 feet must be present in this area. It

is not urged that faulting accounts for this displacement. Such an explanation would not appear illogical, however, in view of the structural features to be considered in the McFaddin-O'Conner area, a field presumably similar to the one in question. Like the possible fault in the Refugio field, the displacement in the Saxet field, should it exist, is down toward the east. Production has been found on both the upthrown and downthrown sides.

Fox.—Drilling has not progressed in the Fox field to the point where an adequate structural picture may be drawn. Paleontological markers and prominent lithologic breaks, however, may be recognized easily, and the thoroughness with which the United Gas System is accumulating information here assures satisfyingly complete structural data at some future date.

McFaddin-O'Conner.—Although drilling in the McFaddin-O'Conner field is in its early stages, some remarkable structural features may be observed.

Figure 3 is a cross section showing probable faulting in the southwestern portion of the field, as indicated by evidence from three wells drilled there by the Humble Oil and Refining Company. Well No. 1, in the center, encountered the top of the *Discorbis* zone at 4,015 feet. The underlying dark, fossiliferous shales of this zone were interrupted abruptly at 4,080 feet by the appearance of green, bentonitic material, quite characteristic of beds found above the *Discorbis* zone. No *Heterostegina* was noted in any of the samples from this well. As shown on the cross section, *Textularia warreni* (Vicksburg?) appears in this well at 5,830 feet.

Well No. 2, the western well, encountered a bed of quartzite at 2,550 feet, the top of the *Discorbis* zone at 3,350 feet, and the top of the apparently normal and well developed *Heterostegina* zone at 3,796 feet. No evidence of *Textularia warreni*, or any of its associates, appears in the well to a total depth of 5,748 feet.

Well No. 3, the eastern well, encountered the tops of the *Discorbis* and *Heterostegina* zones at 4,190 and 4,435 feet, respectively (Fig. 3). No *Textularia warreni* appears to a total depth of 6,860 feet.

Good graphic log correlations bear out the paleontological evidence of the fault suggested in the upper beds of the cross section. A throw of almost 550 feet is indicated.

With reference to the deeper beds, it is repeated that no *Textularia warreni* was found in O'Conner No. 3, the eastern well, to its total depth of 6,860 feet. As indicated on the cross section, *T. warreni* should normally have been found 200 feet, more or less, above that depth. Several possible explanations may be offered for its absence.

Conceivably, the fault already discussed may have increased its throw with depth; or, another fault, post-*Textularia warreni* and pre-*Heterostegina* in age, may be present. Figure 3 suggests the latter explanation, which seems plausible in view of the subsurface faulting already considered in the Refugio field.

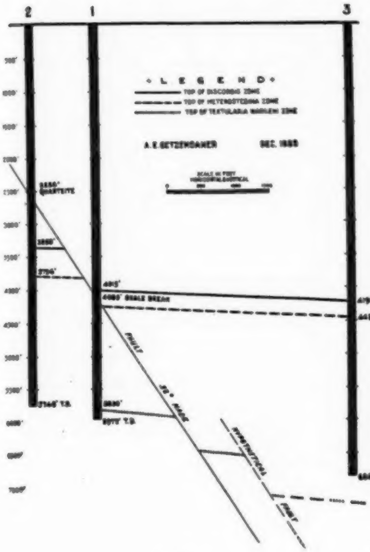

FIG. 3

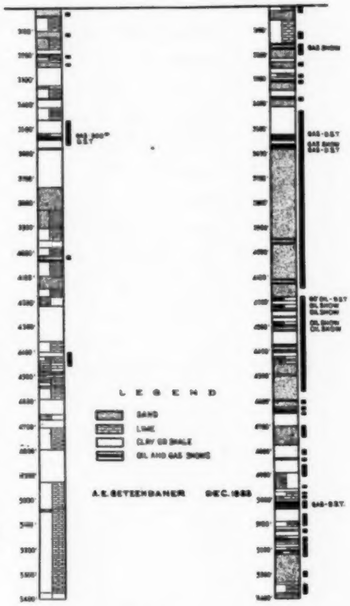

FIG. 4

FIG. 3.—Cross section, showing probable faulting in southwestern portion of McFaddin-O'Conner field, as indicated by depths of paleontological markers in wells drilled by Humble Oil and Refining Company on O'Conner Ranch, Refugio County, Texas.

Fig. 4.—Value of coring, as indicated by comparison of two graphic logs of wells drilled in same field. Both wells were productive, and both were similarly located structurally. Cored intervals are indicated by heavy lines on right side of each log. See text for further discussion.

Greta.—The Greta field, like the Fox field, is in an early stage of development, and it is not deemed advisable, at this time, to attempt to describe the structure.

VALUE OF ADEQUATE CORING

Frequent allusions have been made during this discussion to the difficulty of making correlations between wells which have been in-

adequately cored. In vindication of these statements, Figure 4 is shown. This cross section consists of corresponding portions of the graphic logs of two wells, both productive, both similarly located on the structure, and both drilled in the same field by equally competent drillers. Cores are represented by heavy lines along the sides of the logs. One of these wells was cored almost continuously through the interval shown; the other had very few cores taken from it. In the well cored hole almost 600 feet of nearly unbroken sand is shown, in the same interval which was reported to be mostly shale and lime in the other well. Again, note near the bottom of the log, the well-cored hole shows almost 500 feet of sand with two oil and gas showings, as compared with a reported shale and lime section in the other well. It should also be noted that the well cored hole shows eleven sands which contained oil and (or) gas, against only one showing in the other well, *and that showing was cored.*

The writer has attempted to show, in the preceding paragraph and the cross section (Fig. 4), that direct financial benefit may result from adequate coring and coöperation in securing paleontological information in the drilling of south Texas coastal wells.

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VOL. 18, NO. 4 (APRIL, 1934), PP. 531-542, 3 FIGS.

MISSISSIPPIAN OF COLORADO[1]

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ABSTRACT

Mississippian beds crop out in considerable areas in central, and at a few localities in northwestern, Colorado. They undoubtedly underlie large areas. The character, distribution, and thickness of the deposits are described and their correlation discussed. Charts show the character and variable thickness. Suggestions are made that the term Madison be applied to the lower Mississippian beds in north-central and northwestern Colorado and that the term Leadville be used for the lower Mississippian outcrops in central and southern Colorado. It is believed best to drop the term Millsap from the Colorado nomenclature because of the complications involved. Paleontologic evidence from the sections studied proves that Mississippian rocks are chiefly lower Mississippian and equivalent to Madison of Wyoming. There is evidence, however, to suggest the occurrence of some beds of later Mississippian (Chester) age at a few localities.

The presence of strata of Mississippian age in Colorado has been known from the time of the early exploratory geological surveys, but until recently their extent, thicknesses, and relationships have not been understood. There is still need for much detailed field work and study of well logs before all the details will be known, but it is believed that a fairly clear general picture can now be drawn.

The material given here is based largely on field work by the writers. The literature has been consulted and the available information is presented as interpreted by the writers on the basis of their personal observations. They assume responsibility for all conclusions given which are at variance with those published by other workers.

Many names have been applied to the rocks of Mississippian age in various parts of the state. The following list includes most of these terms.

Mississippian (Lower Carboniferous)
Blue limestone, upper part
Brown limestone (Aspen district)
Leadville limestone, upper part
Lower Carboniferous. The Hayden geologists appear to have used this term as a name for the lowest Carboniferous rocks locally present, without regard to their place in a full Carboniferous section

[1] Read before the Association at the Houston meeting, March 25, 1933. Manuscript received, December 26, 1933. Published by permission of the director of the United States Geological Survey and by permission of the Continental Oil Company.

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Madison limestone
Millsap limestone. Most of the beds to which this term has been applied are considered by Brainerd to be Devonian
Ouray limestone, upper part
Red-beds, in part
Red-wall limestone, possibly lower part
Wasatch limestone, lower part

At present only three of these terms—Leadville limestone, Millsap limestone, and Madison limestone—are in use. The term Leadville is now used as restricted by Kirk.[4] Table I shows the nomenclature in the various sections of the state.

TABLE I

DISTRIBUTION OF MISSISSIPPIAN ROCKS OF COLORADO AND NAMES THAT HAVE BEEN APPLIED TO THEM

Canon City Embayment and West Mountains	*Mosquito Range Sawatch Range*	*South-Central Colorado*	*San Juan Region, Glenwood Springs Region*	*Northwestern Colorado*
				Brazer limestone (probably represented)
Madison ls. 0–85 ft. thick. (Includes Mississippian portion of Millsap limestone of older reports)	Leadville ls. (Upper part of "Blue" limestone of old reports. Upper part of Leadville of *U.S.G.S. Prof. Paper 148*)	Leadville ls. 65–280 ft. (Upper "Blue" limestone of old reports)	Leadville ls. 110–300 ft. (Upper part of Ouray of old reports)	Madison ls. 150–600 ft. ("Wasatch limestone" of some early reports)

In 1904 Girty published his monumental work on the "Carboniferous Formations and Faunas of Colorado."[5] In it he gave an excellent résumé of what was known concerning these formations up to that time. Considering the fragmentary information at his disposal, he showed a surprisingly accurate grasp of the general conditions, and most of his conclusions have been confirmed by later work.

DISTRIBUTION AND CHARACTER

Mississippian deposits crop out in considerable areas in central and southwestern Colorado and undoubtedly underlie large areas in central and northwestern Colorado. It is probable that they extend under most of the plains area in the eastern part of the state. Originally they were even more extensive, and large areas have undoubtedly been removed by erosion in the Sawatch uplift and other mountain ranges of the state. However, it is apparent that they did not cover the entire area of the state, as definite overlapping relations have been observed

[4] E. Kirk, *Amer. Jour. Sci.*, Vol. 22 (1931), p. 239.

[5] *U. S. Geol. Survey Prof. Paper 16.*

by Lovering and Johnson[6] along the southern end and along the western side of the Gore Range, which indicate that at least some portions of the state were not covered by Mississippian seas. However, any land areas which existed in Colorado during the Mississippian epoch were restricted and as coarser clastic sediments are rare in the deposits, the land areas certainly could not have been high. Sandstones are found only at the base of the Mississippian, and are developed only in the northern portions of the Mosquito and Sawatch ranges. In general, the deposits consist of limestones which have a surprising lithologic similarity over large areas.

The deposits vary in thickness from a few feet to about 500 feet, being thickest in the northwestern corner of the state and becoming thinner toward the southeast. Thus in the Front Range they are absent or represented by small and thin erosional remnants. In the Mosquito Range, outcrops show the presence of sediments ranging in depth from 60 to more than 200 feet, and averaging about 160 feet (Fig. 1). In the Sawatch Range there is an even greater variation (Fig. 2). All the fossils obtained indicate early Mississippian age.

STRATIGRAPHIC RELATIONS

Girty,[7] in his résumé, points out the fact that in all the sections from which fossils had been obtained in the central and southwestern part of the state, the lower portions of the limestone series carried a distinctive, unmistakable Devonian fauna, but that the fossils of the upper part indicated a Mississippian age. In the Front Range, however, only Mississippian fossils were found. This led him to believe that the Devonian and Carboniferous portions may not have been deposited strictly consecutively.[8] Later field work has demonstrated the truth of this suspicion. Distinct evidence of a depositional break has been found in every section studied by Johnson in central Colorado, and it has been noted by other recent workers in other localities. A layer of sandstone, quartzite, or sandy limestone marks the break. Above it, there is usually a limestone breccia, consisting of slightly rounded fragments of limestone in a sandy limestone matrix. These features are plainly visible in the outcrops in the Iowa Gulch district of Leadville, on the cliffs at Gilman, and along Frying Pan River at the mouth of Lime Creek. Recent study,[9] which included

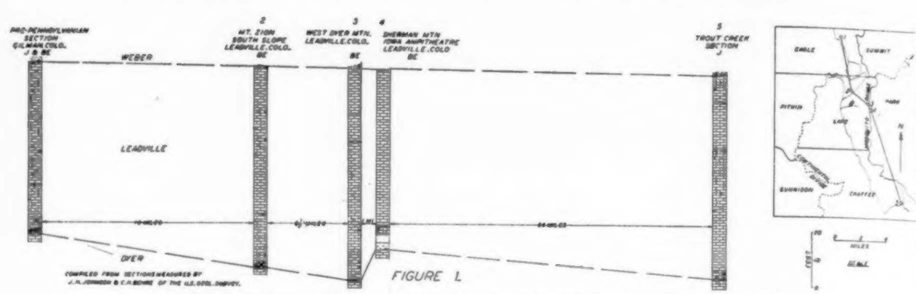
[6] T. S. Lovering and J. H. Johnson, "Meaning of Unconformities in Stratigraphy of Central Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (April, 1933), p. 367.

[7] *Op. cit.*

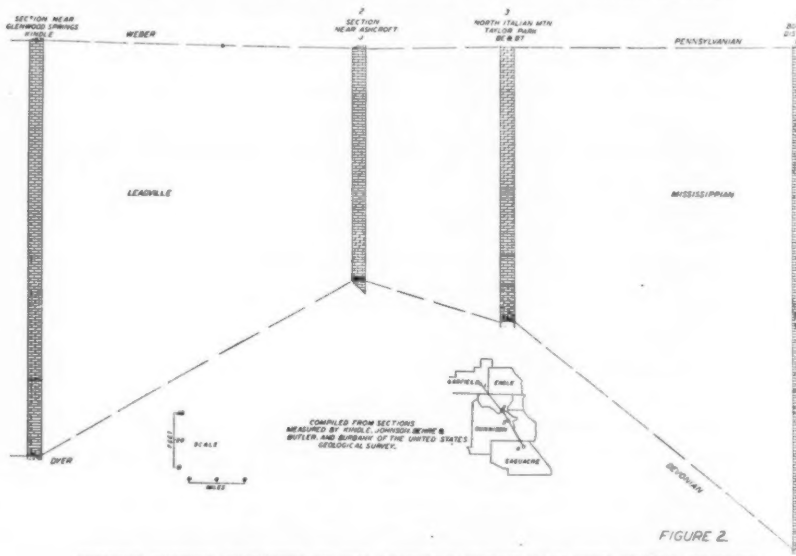
[8] G. H. Girty, *op. cit.*, p. 163.

[9] T. S. Lovering and J. H. Johnson, *op. cit.*, p. 366.

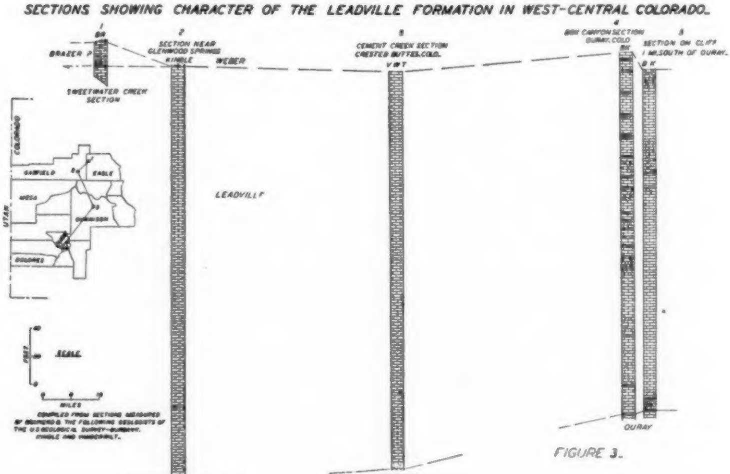
SECTIONS SHOWING CHARACTER OF THE LEADVILLE FORMATION ALONG THE MOSQUITO RANGE, COLORADO.



SECTIONS SHOWING CHARACTER OF THE LEADVILLE FORMATION IN CENTRAL COLORADO.



SECTIONS SHOWING CHARACTER OF THE LEADVILLE FORMATION IN WEST-CENTRAL COLORADO.



FIGURES 1, 2, AND 3

the measuring of large numbers of detailed sections, shows surprising and frequently rapid variations in the thickness of the Devonian limestone beneath this unconformity, indicating a considerable amount of erosion before the deposition of the Mississippian strata. Another important unconformity separates them from the overlying Pennsylvanian beds.

LEADVILLE LIMESTONE

The term Leadville limestone is now being restricted to the Mississippian deposits of central, south-central, and southwestern Colorado. The type locality is in the Leadville district, where it consists of a blue-gray, dense, dolomitic limestone. It occurs in massive layers with some thinner beds and shaly layers at the top. Some beds contain lenses and nodules of black chert. Depositional limestone breccia occurs at the base and sometimes at higher horizons. At a few localities it has been altered to a dense, closely and irregularly banded crystallized dolomite, called "zebra rock" by the miners. West, south, and southwest of the Leadville district the sediments appear to become less dolomitic. The thickness of the formation varies from place to place. Table II shows the thicknesses measured by Johnson and other members of the United States Geological Survey at several sections along the Mosquito and Sawatch ranges.

TABLE II

THICKNESS OF LEADVILLE LIMESTONE (IN FEET)

Sawatch Range		*Mosquito Range*	
Gilman	143	Mount Lincoln	120±
East Lake Creek	23	Hock Hocking Mine	135±
Brush Creek	68±	Mount Zion	145
Woods Lake	172	West Dyer Mountain	62+
Frying Pan River	85+	Sheridan Mountain	126
Smuggler Mountain	0	Horseshoe Creek	175
Aspen Mountain	60	Weston Pass	290
Tourtolette Park	103	Trout Creek	137
Ashcroft	165	Upper Badger Creek	180
North Italian Mountain	185	Arkansas River	225
Cement Creek	325		

These variations in thickness have probably resulted more from erosion in the late Mississippian and early Pennsylvanian than from original differences in amount of deposition. The following hitherto unpublished section by C. H. Behre, of the United States Geological Survey, illustrates the character of the material at the type locality.

COMPOSITE SECTION ON SOUTH SLOPE OF MOUNT ZION, NEAR LEADVILLE, COLORADO

	Thickness, Feet
White porphyry sill	
White porphyry at top of section	(Tertiary intrusion)
Leadville limestone	
1. Conglomerate of limestone boulders and pebbles in calcareous matrix. Individual boulders not well rounded. Some black chert pebbles. In middle, 1 foot of coarse, yellowish weathering, arkosic sandstone, with calcareous cement	5
2. Blue limestone with black chert lenses and spheres, and local shaly layers	37.5
3. Blue-gray limestone, much like above, but locally recrystallized into "zebra rock"	14
4. Dense, cherty, dark blue-gray layers (secondarily silicified?)	5.5
5. Same as 6, but free from chert	23
6. Same as 7, but beds not coarsely crystalline	40
7. Altered, coarsely crystalline blue limestone. Light blue-gray, local black chert lenses. Weathers to "checkered" color pattern which brings out dark splotches	20
Total	145
Chaffee formation (Upper Devonian)	
Dyer dolomite member	

Southward along the Mosquito Range and beyond into the Bonanza district, the deposits become less dolomitic, and in some places, for example, near Trout Creek, the upper portion of the formation contains several layers of depositional limestone breccia. In the Bonanza district the Leadville limestone[10] comprises alternations of massive, unevenly bedded and thin-bedded, fine-grained, blue-gray limestone, which ranges from 350 to 400 feet in thickness. The basal 10 or 15 feet consists of thinly bedded shale and shaly limestone. Above these the limestone abruptly becomes very massive and unevenly bedded with warped or curved bedded planes 1–3 feet apart. These massive beds are free from chert and continue upward for about 30 feet, where they pass into thinly bedded limestone. About 80 or 100 feet above the base, there is a coarse black dolomite containing much black chert. Above this, the limestone again becomes massive, but carries abundant concretions of black chert. The uppermost beds consist of medium or thinly bedded, soft, blue limestone, probably separated by thin streaks of shale.

At Gilman and Red Cliff, about 25 miles north-northwest of Leadville, the deposits are similar in appearance to those in the Leadville district. At Gilman they attain a thickness of 143 feet. The section below, measured by J. H. Johnson and C. H. Behre, Jr., of the United States Geological Survey, shows the character of the material.

[10] W. S. Burbank, *U. S. Geol. Survey Prof. Paper 169* (1932), pp. 10, 12–13, Pl. 5.

SECTION MEASURED AT GILMAN, COLORADO

Description	*Thickness in Feet*
Weber (?) formation	
Leadville limestone	
Light gray to almost black dolomitic limestone with irregular layers and masses of "zebra lime" and black chert nodules and stringers	110
Very sandy limestone with fragments of black chert and a few limestone pieces	8
Sandy (gritty) quartzite	2
Limestone conglomerate in sandy matrix	3
Light gray to brown sandstone	2
Total	125
Chaffee formation	
Dyer dolomite member	

Southward along the west side of the Sawatch uplift, the formation is represented entirely by limestone which is somewhat dolomitic at the northern end but becomes less dolomitic toward the south until, in the Aspen district, it is an almost pure limestone (Fig. 2).

As shown in Table II, thicknesses vary greatly. In the areas between Woody Creek and Roaring Fork the Leadville seems to be absent. The mines in Smuggler Mountain show Weber (?) shales resting on the Dyer dolomite. South of Roaring Fork the Leadville reappears and thickens rapidly, attaining a thickness of about 175 feet in the vicinity of Ashcroft 9 miles south of Aspen, and about 300 feet along Cement Creek in the Anthracite Quadrangle.[11]

In the San Juan region the Mississippian deposits include only the upper portion of the Ouray limestone of the early reports. According to Burbank,[12] the Mississippian in the vicinity of Ouray includes a lower portion about 55 feet thick, consisting of dark blue-gray or brown unevenly bedded limestone with interbedded gray crystalline limestone in sandy layers. It is sparingly fossiliferous. Above this lower portion the formation consists largely of massive gray or brownish gray crystalline limestone alternating with beds of limestone breccia containing partings of red shale. Near the top some gray crystalline beds are found which are very fossiliferous. At a number of horizons chert occurs in nodules and thin layers. Toward the top the shale layers and breccias become more prominent and the beds acquire a coarser texture. The breccias consist of limestone fragments in a red shale matrix. The uppermost beds consist of alternations of shale and impure ferruginous limestone. These upper beds have been re-

[11] T. S. Lovering and J. H. Johnson, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 4 (April, 1933), p. 367.
J. W. Vanderwilt, *Proc. Colorado Sci. Soc.*, Vol. 13 (1933).

[12] W. S. Burbank, "Revision of Geologic Structure and Stratigraphy in the Ouray District of Colorado," *Proc. Colorado Sci. Soc.*, Vol. 12 (1930), pp. 155, 160, 161.

moved by erosion in most places. The total thickness is about 235 feet (Fig. 3).

Similar beds in the Glenwood Springs region are about 272 feet thick. They include 5 feet of dolomitic limestone above some shales, and 180 feet of limestone at the top.[13]

J. W. Vanderwilt, of the United States Geological Survey, recently measured sections at the head of Yule Creek southwest of Glenwood Springs where the limestones are altered to marbles by local metamorphism. He found the Mississippian on Yule Creek and near Treasure Mountain to include about 274 feet of material.

MISSISSIPPIAN OF NORTHWESTERN COLORADO

In northwestern Colorado the Mississippian beds are exposed along the flanks of the Uinta Mountains and along the crest and flanks of the Cross Mountain and Juniper Mountain uplifts. In Split Mountain Canyon about 400 feet of dense gray limestone is exposed in the bottom of the canyon. The unit closely resembles the Madison limestone of western Wyoming in lithology and fauna and has been called by that name. Overlying this limestone there are about 108 feet of cherty limestone and sandy and conglomeratic limestone that the senior writer has considered younger than true Madison, but older than Pennsylvanian. It is tentatively correlated with the Brazer limestone (upper and middle Mississippian), which is well developed in southeastern Idaho.

Along Vermilion Creek in northwestern Colorado, 585 feet of Mississippian limestone occurs.[14] This is gray in color but becomes buff on weathering. It is thick to thin-bedded and in a few places at the base there are some sandstone and small quartz pebbles. The limestone has been correlated as equivalent to the Madison of Wyoming.

Along Sweetwater Creek north-northeast of Glenwood Springs (about Sec. 3, T. 4 S., R. 86 W., Eagle County), there occurs above the lower Mississippian limestone 17 feet of gray, brown, and yellowish brown limestone which is irregularly bedded and slightly cherty with breaks of gray shale. These beds are lithologically unlike the underlying limestone and are separated from the overlying Pennsylvanian sediments by a distinct erosional unconformity. They are considered by Brainerd as Mississippian younger than Madison and probably equivalent to the Brazer.

[13] J. W. Vanderwilt, *Proc. Colorado Sci. Soc.*, Vol. 13.
E. M. Kindle, *U. S. Geol. Survey Bull. 391* (1909).

[14] J. D. Sears, *U. S. Geol. Survey Bull. 751* (1923), p. 281.

MILLSAP LIMESTONE

Along the southern end of the Front Range and the eastern side of the Wet Mountains there are remnants of Mississippian and Devonian limestones to which the term Millsap has been applied. The type locality is Millsap Creek in the southern part of the Pikes Peak Quadrangle. Here the deposits consist of thin-bedded limestones which Brainerd[15] has recently included in his Williams Canyon limestone, of *probable* Devonian age. Above the Williams Canyon limestone is a distinct erosion surface upon which occur chert fragments containing Mississippian fossils. However, remnants of definitely Mississippian limestones were found at several localities resting on the Williams Canyon limestone and separated from it by a distinct erosional unconformity. Such remnants occur from the vicinity of Beulah, in the southwest corner of the Pueblo Quadrangle, and northward to Perry Park. The deposits consist of thick, massively bedded white-to-gray limestone. Many outcrops are stained red and pink by wash from the overlying Pennsylvanian Red-beds, and in several places the bedding planes are not distinct. The formation usually makes steep cliffs and escarpments, the upper part is often brecciated from pre-Pennsylvanian weathering, and, locally, old sink holes and caverns filled with Pennsylvanian material occur. A good example of these fossil caves may be observed in the cliffs west of Beulah. The thickness of the Mississippian limestone present varies from a thin edge up to 200 feet in the various localities where present, averages between 25 and 30 feet, and is absent in many places.[16] Numerous chert nodules occur in the upper layers.

It is interesting to note that although no outcrops of the Mississippian are known on the eastern flanks of the Front Range north of Perry Park, numerous chert pebbles which contain Mississippian fossils have been found in the basal Pennsylvanian deposits, suggesting that Mississippian deposits originally extended northward into Wyoming, but were largely removed before the deposition of the Pennsylvanian. However, some such pebbles have been found in the early Tertiary beds of northeastern Colorado. This may mean that some Mississippian material persisted along the northern Front Range until after the Laramide revolution. Fossils obtained from the Mississippian in the Pikes Peak, Canon City, Pueblo, Colorado Springs, and Castle Rock quadrangles have been discussed by Girty.[17]

[15] A. E. Brainerd, H. Baldwin, and I. A. Keyte, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 4 (April, 1933), pp. 387–92.

[16] A. E. Brainerd, H. Baldwin, and I. A. Keyte, *op. cit.*, pp. 391–92.

[17] G. H. Girty, *U. S. Geol. Survey Prof. Paper 16*, pp. 169, 227, 228.

It is strongly recommended that the old term Millsap be dropped, as has already been suggested by Brainerd, Baldwin, and Keyte,[18] because this term is preoccupied in Texas for deposits of a different age and because the deposits in east-central Colorado to which Millsap has been applied consist largely of pre-Mississippian sediments.

Very little is known concerning the Mississippian beds of eastern Colorado, as they are covered by a thick series of later deposits. However, a few wells have revealed the presence of Mississippian sediments in the southeastern part of the state and in the adjoining portion of Kansas. Thus, the Jones *et al.* Boise well No. 1, in Sec. 22, T. 34 S., R. 42 W., Baca County, entered Mississippian rocks at a depth of 4,920 feet and penetrated them 35 or 40 feet before the well was abandoned. The Pipe Springs well of the Marland Company in Sec. 27, T. 27 S., R. 49 W., found a thickness of 385 feet of Mississippian rocks, from a depth of 5,515 feet to 5,900 feet, before going into the underlying Ordovician. The Two Buttes well in Sec. 30, T. 27 S., R. 45 W., Prowers County, entered Mississippian rocks at a depth of 4,990 and was still in them at 5,220 when the drilling ceased. The McCray Ransom No. 1, in Sec. 5, T. 26 S., R. 41 W., Hamilton County, Kansas, entered the Mississippian at a depth of 5,320 and had penetrated it for 140 feet when the well was abandoned. The age determinations were based on microscopic studies of the well samples by the oil companies. These facts indicate that the Mississippian may underlie a considerable area of eastern Colorado.

GENERAL RELATIONSHIPS OF MISSISSIPPIAN DEPOSITS

The Mississippian rests unconformably on the older beds, in most places on Devonian beds, though in northwestern Colorado it lies on lower Paleozoic or on pre-Cambrian.

At the top of the Mississippian sediments there is everywhere a pronounced break representing a considerable length of time, during which large but varying amounts of the Mississippian deposits were removed. Locally the old limestone surface was eroded into sink holes and a semi-karst topography. Good examples of solution effects can be observed in the mines at Gilman and in the Aspen district where the overlying Pennsylvanian shales have filled sink holes and other irregularities in the old surface.[19] Brainerd[20] has noted similar conditions in the Wet Mountain area. The paleontologic evidence so far

[18] *Op. cit.*, pp. 387–91.

[19] J. H. Johnson, *U. S. Geol. Survey Prof. Paper* (in preparation).

[20] A. E. Brainerd, H. Baldwin, and I. A. Keyte, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 4 (April, 1933), p. 391.

obtained shows the Leadville limestone to be of early Mississippian age, equivalent to the Madison of Wyoming and probably equivalent to the Kinderhook and possibly the lower Burlington of the Mississippi Valley. So far no fossils of Chester age have been obtained, but Brainerd and Baldwin found some beds between the lower Mississippian limestone and the Pennsylvanian at Split Mountain Canyon and along Sweetwater Creek north of Glenwood Springs, Colorado (Fig. 3), which they considered might represent remnants of younger Mississippian deposits such as are found farther north in Idaho and Wyoming. Laboratory study of well samples from some of the wells in southeastern Colorado indicate the presence of some sediments of Chester age above the lower beds in that region.

CONCLUSION

The various names used in the literature for the lower Mississippian beds in Colorado have been listed herein. Four names, Leadville, Ouray, Millsap, and Madison, have been most commonly used and recognized. Recently the term Ouray has been restricted to the Devonian and the term Millsap has been dropped.

The lower Mississippian in Colorado is essentially equivalent to the Madison formation of Wyoming, Montana, southeastern Idaho, and northern Utah, the Pahasapa formation of the Black Hills, the Redwall of Arizona, the Lake Valley beds of New Mexico, and part of the Boone formation of Missouri.

Inasmuch as the name Madison was first applied to the lower Mississippian limestone of the northern Rocky Mountains, and is now used in much of the Rocky Mountain region, it seems that the term should be used for this series in Colorado. The term Leadville, however, has been used by the mining men in central Colorado for almost as long a period, and is now firmly entrenched in both literature and local use.

The junior writer indicates that in the opinion of the United States Geological Survey the name Leadville should be applied to the lower Mississippian limestone in the mining districts and on the southern Front Range in Colorado, and the name Madison to the lower Mississippian limestone in northern and northwestern Colorado.

The senior writer believes that, inasmuch as the name Madison was the first to be applied to the lower Mississippian deposits in the Rocky Mountain region and is more widely known and more widely used by geologists in general, it should be applied to the lower Mississippian deposits throughout Colorado except in the mining districts where the term Leadville has become firmly entrenched, and

that even here the equivalence should be thoroughly understood. There may be, as has been stated, slight lithologic and even faunal differences, but the senior writer believes such differences are inevitable in any widespread deposit and are to be considered common rather than exceptional. The use of the name Madison for the lower Mississippian rocks in one part of Colorado and Leadville in another is confusing, while the use of the name Madison for these deposits throughout the entire Rocky Mountain area, Colorado included, is more simple.

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GEOLOGICAL NOTES

DISCOVERY OF VALENTINE (LAROSE) DOME, LOUISIANA, BY REFLECTION SEISMOGRAPH

During the past year the question has been asked the writer a number of times, "Has reflection seismograph work been wholly responsible for a single discovery of a dome on the Gulf Coast of Texas or Louisiana, or has previous refraction work, torsional-balance work or surface indications been primarily responsible?" In answer to this question the writer knows definitely of one case where the use of the reflection method of dip shooting was wholly responsible for discovery. That is The Barnsdall Oil Company's Valentine or LaRose prospect in T. 17 S., R. 20 E., Lafourche Parish, Louisiana.

Without any previous knowledge of the area, The Barnsdall Oil Company assumed an obligation to do geophysical work on a plantation consisting of 48,000 acres. The services of a consulting firm of geophysicists were engaged. The work was extremely hazardous and difficult because of the vast swamp area, but the work on the 48,000-acre block indicated the beds to be rising south toward Bayou Lafourche. Other leases were obtained and the work continued in that direction until a dome of considerable size was well defined.

Following this work, The Barnsdall Oil Company drilled their Harang well No. 1, reaching the Lower Oligocene at 6,730 feet and salt at 6,976 feet, with several important showings of oil and gas in the Lower Miocene and Oligocene.

The results of this project tend to show that a virgin area of considerable size can be explored by reflection seismograph work from a reconnaissance standpoint without entailing too much expense. The actual time in the field was less than 3 months and the area covered was 60,000–70,000 acres, of which more than half was marsh land.

GEORGE S. BUCHANAN

HOUSTON, TEXAS
February 9, 1934

OCCURRENCE OF SIDERITE IN CAP ROCK AT CARLOS DOME, GRIMES COUNTY, TEXAS

The identification of siderite in the cap rock of the recently discovered Carlos salt dome is believed to be the first recognition of this mineral in cap rock.

The Carlos dome is in the west-central part of Grimes County, Texas, almost due west of the town of Carlos, about 14 miles southeast of Bryan, and the same distance northwest of Navasota.

The nearest salt dome is Clay Creek, in Washington County, about 25 miles southwest.

The late E. D. Phillips found gas seeps and beds of paraffine dirt, and recommended that a block be taken in this area. Later geophysical investigation, both seismic and magnetic, confirmed the presence of a dome.

The first well, the Humble Oil and Refining Company's Templeman No. 1, located in the G. W. Seaton Survey, was commenced October 1, 1933, and was completed November 6, 1933. The following is a log of this well.

Depth in Feet	
114	Surface clay and sand
200	Sand and clay
408	Sand and shale
558	Sand
778	Sand and shale
899	Sandy shale
900	Rock
901	Rock
932	Shale
955	Shale
990	Sandy shale
1,031	Lignite
1,075	Shale
1,115	Sandy shale
1,117	Rock
1,156	Sandy shale and boulders
1,159	Rock
1,160	Rock
1,190	Shale
1,240	Sand and shale
1,650	Shale
1,670	Shale
1,860	Shale and shell
1,982	Sand and shale
1,983	Rock
2,017	Shale
2,051	Shale
2,056	Rock
2,090	Shale and shells
2,095	Rock
2,176	Shale and shells
2,223	Shale, shell, and sand
2,256	Hard sandy shale and shells
2,267	Sand
2,281	Sand
2,349	Sandy shale
2,352	Rock
2,364	Shale
2,517	Sandy shale
2,535	Sandy shale
2,614	Brown shale
2,629	Shale
2,640	Sandy shale
2,668	Shale
2,727	Sandy shale
2,887	Sandy shale and lime
2,919	Sand
2,950	Shale
2,955	Sand
3,015	Sandy shale
3,240	Sandy shale and lime
3,274	Shale and shells
3,277	Rock
3,278	Rock
3,393	Sandy shale and lime
3,403	Hard sand
3,422	Sand
3,520	Hard sand
3,538	Hard sand
3,540	Rock
3,550	Rock
3,560	Hard sandstone
3,567	Sand
3,605	Hard sand
3,621	Hard sand
3,640	Hard sandy lime
3,676	Hard sandstone
3,724	Hard sand and limestone
3,730	Hard sand and lime
3,770	Hard sandy lime
3,780	Hard sand, lime, and anhydrite
3,820	Hard sandy lime
3,830	Anhydrite and lime
3,859	Anhydrite
3,877	Anhydrite
3,918	Anhydrite
3,978	Anhydrite
4,035	Anhydrite
4,038	Anhydrite
4,080	Salt
4,150	Salt
4,170	Salt (total depth)

The first evidence of cap, hard calcified sandstone, was cored at a depth of 3,537 feet in this well. Limestone fragments in cuttings were noted at 3,616 feet, and a core of limestone was also obtained at this depth.

Brown siderite with numerous cavities was cored at 3,770–80 feet. Anhydrite was cored at 3,820 feet, and continued to 4,038 feet, where salt was logged. The salt was first cored at 4,089 feet and the well was abandoned at 4,170 feet, still in salt.

Samples of the limestone and siderite cores were analyzed by F. W. Jessen, of the Humble Oil and Refining Company, with the following results.

		Percentage			
Material	*Depth in Feet*	*Iron*	*Calcium*	*Magnesium*	*Carbonate*
Limestone	3,616–21	1.61	36.17	1.71	60.26
Limestone	3,666–76	Trace	39.19	Trace	60.49
Siderite	3,770–80	36.60	0.87	6.10	57.02

In this analysis the iron, calcium, and magnesium are reported as elements, while the carbonate is reported as the radical CO_3.

Portions of the core from 3,770–80 feet were sent to W. Harold Tomlinson, of Swarthmore, Pennsylvania, for petrographic analysis. Tomlinson reports the sample as a mineral somewhere between ankerite and siderite. He also reports finding galena, sphalerite, quartz, and a few crystals having optical properties of anhydrite.

From the chemical analysis the writer believes the material is siderite with minor impurities.

The followlng is an analysis of a salt core at 4,167–70 feet.

	Percentage
Chlorine	58.5
Sulphate	4.2
Calcium	5.3
Magnesium	1.6
Sodium and insoluble residue (by difference)	30.4
	100.0

The salt seems to be very porous, as drilling mud has penetrated almost to the center of the core.

The residue remaining after the salt was dissolved consists of flat tabular and short pyramidal crystals of anhydrite, a few crystals of dolomite, quartz, and metallic sulphides. A rosette of quartz crystals was also noted.

Tomlinson, in his report on the core from 3,770–80, also states:

> This sample does not give any particular evidence as to its origin. It is most probably a portion of a limestone bed which was invaded by mineralizing waters carrying iron salts which would replace the limestone, and the

lead and zinc were precipitated by reduction through organic matter in the limestone. The sample does not show any evidence of being a sedimentary siderite bed, that is, a bed originally precipitated as siderite.

The limestone cap has evidently been in contact with waters saturated with iron sometime during its geologic history, possibly during the Wilcox.

There is approximately 300 feet of brownish gray, lignitic, sandy shale and argillaceous sands above the cap rock, which are referred to the Wilcox. The information obtained to date suggests that this dome has not been active since Wilcox time.

F. W. Rolshausen

Humble Oil and Refining Company
Houston, Texas
March 1, 1934

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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DISCUSSION

JAMIN EFFECT IN OIL PRODUCTION

Randall Wright[1] states that the term "capillarity" in the sense in which I[2] use it is a "misnomer." Wright's argument that capillarity means "hair-like" does not, I believe, have any direct bearing on the subject, as it is often seen that the original meaning of a word may become obsolete or that the word may gradually assume various meanings, so that the original meaning becomes obscured. However, I use the term to mean: "the effect of the intermolecular attractions when two or more phases interfere." It might be remarked that only three phases are known, but the meaning I wish to express is that there may be more than one liquid. One of the first results of intermolecular attraction is the existence of the interfacial energy. I prefer the word "interface" to "surface" in this respect in order to emphasize that I do not preclude the energy of the interfaces of two liquids and of a liquid and a solid. Furthermore, I prefer "energy" to "tension" because the apparent tension is the result of the energy and because when using the word "tension" the factor "heat" is excluded.

It seems to me that I am not far wrong. For instance, H. Freundlich wrote a book on colloidal chemistry, which was entitled: *Kapillarchemie.*

Long ago the action of intermolecular attraction, although not understood and explained at first, was observed in narrow tubes and for this reason it was called "capillarity." But when it was understood that the capillary rise was caused by the intermolecular attraction, the use of the term capillarity was extended to cover all the effects of such attractions.

In 1842, long after the capillary rise had been observed, Poiseuille used capillary tubes in order to study the laws governing the flow of blood through the veins. This had often caused confusion, but I do not think that this confusion invaded exact handbooks on physics. In my opinion, the term "capillary flow," although not absolutely wrong, should be avoided. The terms "lamellar flow" and "viscous flow" are to be preferred.

There is one more question of wording. On pages 196 and 197 of my first quoted paper, I wrote regarding Jamin's experiments:

> With this experiment, however, not all precautions were taken. The tube was filled by suction at one end, while a finger wrapped with a moist white cloth was alternately pressed on the free end of the tube and withdrawn. Jamin concluded from his experiments that in a narrow tube a number of gas bubbles are able to cause a considerable resistance to the flow of a liquid for a long time. Thirteen years later Plateau proved that Jamin had not taken all the necessary precautions with his experiments. With the precautions Plateau took, the effect was much less. The writer believes that the Jamin effect would not be observed in a cylindrical tube, if it were possible to work more accurately than Plateau did.

[1] Randall Wright, "Jamin Effect in Oil Production," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 12 (December, 1933), pp. 1523 and 1524.

[2] J. Versluys, "Can Absence of Edge-Water Encroachment in Certain Oil Fields Be Ascribed to Capillarity?," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 2 (February, 1931), p. 197.

On page 1522 of his paper, Wright quotes only the last sentence and comments on this one sentence as follows: "The meaning of the phrase 'more accurately' is not clear."

Certainly my words would have been clearer if I had written "still more accurately." I apologize for the omission of the word "still": when writing one should do it in such a way that the reader is saved all possible trouble. I am afraid, however, that the reader of Wright's paper may conclude that I failed to state the arguments which have led to my conclusion.

When dealing with the flow of oil, gas, and water through the pores of a layer, Wright deals only with one of my papers.[3] I have elaborated, however, on what I still call "capillarity" in a more recent paper.[4] The reader of Wright's paper may be referred to this article, too.

It seems to me that one of Wright's conclusions: "The Jamin effect does not operate to retard flow of petroleum toward a well" quite covers mine. Another conclusion of Wright's paper is:

> encroachment of edge water may be retarded by that effect under certain conditions, as where pores are large and pressure comparatively low.

I regret that I did not know that Wright would discuss this subject, or I would have sent him preprints of my papers read at the World Petroleum Congress, held in London in July, 1933.[5]

These preprints were dispatched about that time and excerpts were printed in the *Oil and Gas Journal* of August 10, 1933, page 16. In these papers were expressed my views concerning the retardation of edge-water encroachment caused by the gas bubbles in the formation after part of the oil has been expelled by gas. It would have been interesting if Wright had given his opinion on these papers at the same time. My views are that when edge water invades the depleted zone, that is to say the zone where oil has been partly displaced by gas, the advancing edge water has to displace oil and also to recharge the gas-filled spaces. Thus, in this respect, I also deny the Jamin effect.

J. VERSLUYS

AMSTERDAM, HOLLAND
January 12, 1934

Doubtless by mischance Versluys misquotes me in saying, "Wright's argument that capillarity means 'hairlike' . . ." I wrote: "capillary means 'hairlike.' "

In my paper there was a suggestion that a clearer distinction be made between the usages of the terms "capillarity" and "capillary flow." This suggestion, containing the definition alluded to above, was relegated to footnote importance; it was intended to point out the general lack of uniformity in usages of these terms and had no bearing on the reality of the Jamin effect.

Jamin action retards flow. Capillarity causes flow. It appears to me that

[3] *Op. cit.*

[4] J. Versluys, "Factors Involved in Segregation of Oil and Gas from Subterranean Water," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 9 (September, 1932), pp. 924-42.

[5] J. Versluys, "The Sources of Energy Involved in Propagation of Oil Towards a Well" and "Principles Governing the Location of Wells with Respect to the Structure."

the two phenomena should be differentiated. Hence my designation "misnomer" for Versluys' usage of "capillarity" in his title, "Can Absence of Edge-Water Encroachment in Certain Oil Fields Be Ascribed to Capillarity?"

King's work (cited in my article) is but one of many researches dealing with those water movements in artesian environment which are best described as "capillary flow"; this is flow through fine tubes (porous formation) and away from pressure.

Versluys' interesting discussion of the obscuration of the original meaning of the term "capillarity" seems to point toward the possibility of two opinions as to its breadth until such time as agreement in its usage is general.

Quoting himself, Versluys mentions Plateau. If the latter had done perfect work it could not alter the fact that the Jamin effect can and does occur as is shown by the work of Jamin and Herold (both cited in my article), and my own. For this reason the bearing of the phrase "more accurately" is not clear.

My conclusion as to the non-retardation of migrating petroleum by Jamin action, mentioned by Versluys as covering his, is the result of laboratory investigation. I have not seen mention of laboratory work by Versluys on this subject. Further, it may be recalled that Herold has published no retirement from his stand on the importance of the Jamin effect, a position questioned by Versluys on theoretical rather than experimental grounds.

Of course I was aware of Versluys' 1932 paper in the *Bulletin*.

RANDALL WRIGHT

SAN DIEGO, CALIFORNIA
February 5, 1934

NATURAL GAS IN AUSTRALIA AND NEW GUINEA

CORRECTION

In the article, "Natural Gas in Australia and New Guinea," in the February, 1934, *Bulletin*, the sentence beginning on the 6th line from the end of page 240, referring to oil found in association with artesian water at Longreach, should have been printed as follows:

In 1929 a well was drilled near the water well in search for oil, and oil was obtained.

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REVIEWS AND NEW PUBLICATIONS

"Untersuchungen über die Sedimentationsverhältnisse des Schwarzenmeeres und ihre Anwendung auf das nordkaukasische Erdölgebiet" (Investigations of Conditions of Sedimentation in the Black Sea and their Application to the Oil Fields North of the Caucasus). By DORA WOLANSKY. *Geologische Rundschau*, Band 24, Heft 6 (1933) pp. 397–410.

The brief article under review furnishes an interesting summary of the data secured by Archangelski and his associates during several years devoted to an investigation of the Black Sea, its deposits, its geological history since the Lower Pliocene, and the relations between its sediments and the oil measures of the district north of the Caucasus. An outstanding achievement of the investigation was the securing of cores in different parts of the sea bottom to depths of 3 and 4 meters. These show the presence in all the bottom deposits of a fine, seasonal lamination, and indicate that on the average 1 centimeter of material has accumulated in about 50 years. Changes in type of sediment have also occurred in longer periods of 1,000–3,000 years. These changes are referred to risings and sinkings of the northern and northwestern margins of the sea.

The cores also show that in the deeper parts of the sea there is an important type of sediment which is never found on the bottom, but occurs buried to a slight depth in the bottom deposits. This is a black sapropel, said to be similar in all respects to the lake sapropel of northern Europe. It is interbedded with the other types of sediment, which are described as gray clay, calcareous ooze, calcareous diatom ooze, and sand. The sand just mentioned, which is a deep-sea deposit, is found in very fine laminae where currents are active. About the margins of the sea there are of course more normal deposits, such as oyster banks, beach sand, *Mytilus* mud, and others.

The only living organisms that have been detected in the deeper parts of the sea are two kinds of bacteria, one of which generates limestone in minute crystals, the other pyrite. At least one other type of bacterium is thought to be present also, but has not yet been isolated.

By comparison of the Black Sea sediments with oil measures of the Grozny and other oil fields, Archangelski and his associates have thrown a flood of light not only on the conditions of deposition of the oil measures, but also on the problem of the origin of oil. In the oil measures, which are many hundreds of meters thick, and which range in age from Middle Oligocene or Upper Miocene, they find all of the types of sediment now accumulating in the Black Sea, except the sapropel. This last type is replaced by a "kerogen" shale, which is in some places associated with free oil, especially where it is porous or filled with fractures. In other places it has yielded its oil to interbedded sandy lenses. Archangelski believes that the genesis of the oil is due to a splitting of the sapropel into "kerogen" and oil, and that there is a definite relation between the amounts of the two that are produced. He finds that if the amount of kerogen drops below a certain percentage, commercial quantities of oil are not to be expected in an area.

The genesis of the oil is attributed to bacterial activity. Archangelski believes that an as yet undiscovered form, called "*Micrococcus petroli*," finds life pleasant in the poisonous, anaerobic environment of the Black Sea and similar depressions, and by its life processes changes sapropel to "kerogen" and oil. During the compaction and folding of the strata he supposes that the oil is forced into the less compressible sandy lenses of the sedimentary series, and becomes more or less well adjusted to their structure.

The data contained in the article under review are abstracted from six Russian articles, to which references are given. They suggest that the Soviet geologists have at last succeeded in formulating a theory of the origin of oil which is not based entirely on extrapolations from laboratory investigations, but includes the historic factor which tends to make an investigation geological. The data suggest, further, that geologists of the western world have probably missed a great deal during the last 10 years by their inability to follow closely the activities of their Russian colleagues. Perhaps the next session of the International Geological Congress, to be held in Moscow two and a half years hence, may assist in breaking down the barriers that have existed and in furthering that worldwide exchange of ideas that is a necessity if scientific research is to advance as rapidly and satisfactorily as it might.

R. D. REED

LOS ANGELES, CALIFORNIA
February 10, 1934

"Oil and Gas in Western Canada" (Second Edition). By G. S. HUME. *Geol. Survey of Canada Econ. Geol. Ser. 5.* Ottawa, Ontario (1933). 359 pp., 26 illus. Paper. 6.5×9.75 inches. Price, $0.75.

This volume takes the place of the first edition published in 1928. Numerous additions and alterations have been made and the price has been increased from $0.25 to $0.75. The paper used in the second edition is much more suitable and more practical than that used in the first.

Chapter One, "Origin and Accumulation of Oil and Gas," is covered in 18 pages and necessarily represents a mere outline of the important and elementary principles. This chapter is of great use to the layman but of little value to a geologist who is conversant with the literature.

Chapter Two, "Geophysical Methods of Locating Oil and Gas," is covered in 8 pages. This subject is also treated in an elementary manner and should be of great use to the layman. The torsion balance is given an amount of space out of proportion to the other geophysical methods. This is particularly true with respect to Western Canada where the torsion balance has proved to be of very little value.

Chapter Three, "Physical Features, Geological Structure, and Stratigraphy of the Great Plains and Foothills," covers 39 pages and is of particular interest to the geologists working in Western Canada. In this chapter Dr. Hume puts forth his ideas and theories on the structure of the Foothills and the Plains. The latest division of the Blairmore and Kootenay is given and the term "Alberta shale" is used to supplant "Benton" or Colorado shale, much against the consensus of opinion among the petroleum geologists. Russell's new name "Blood Reserve sandstone," to replace the name "Fox Hills sandstone" is also followed against the petroleum geologists' opinions. The

most recent trend of thought on the structure of the Foothills area is put forth and several very recent conceptions with respect to this problem are discussed. The problem of source rock is also touched upon in this chapter and is of particular interest.

Chapters Four to Ten include the following: "Southern Plains of Alberta," "Central Plains of Alberta," "Northern Plains of Alberta," "Plains of Manitoba and Saskatechewan," "Northwest Territories," and "British Columbia." These chapters are merely extracts from previously published geological survey reports with up-to-date alterations and additions (Summary Reports, Memoirs, et cetera). At the end of each chapter a bibliography is added, which is of considerable value to anyone wishing to obtain more detailed information. Numerous references to the D. B. Dowling Memorial Symposium are made, and many of the districts are discussed by other members of the Geological Survey.

The Appendix consists of a list of wells drilled in Western Canada, including Manitoba, Saskatchewan, Alberta, British Columbia, and the Northwest Territories. In the list appears the name of the well, the legal description, total depth drilled, elevation, and notes regarding production.

Figure 16, the structure contour map of the Bow Island gas field, is open to criticism since some geologists do not agree with that interpretation. The same may be said for Figure 17, representing the structure contour map of the Medicine Hat gas field.

There is no introductory chapter in the publication setting forth its object or aim. The writer believes that this volume is of great value to a geologist coming into the area for the first time, to be used as a source or reference book. It is of considerable value to oil operators who wish to get some of the fundamental ideas of petroleum geology, geophysics and the general location of the few oil fields of Western Canada, and the locations where exploration has already been carried on. Chapter Three, on the "Physical Features, Geological Structure," et cetera, is by far the most important and interesting part of the publication for geologists working in this area.

Although the Table of Contents is very comprehensive and might take the place of an Index, the absence of the latter is a handicap with respect to Chapter Three. The number of illustrations, such as contour maps and cross sections, is quite inadequate and could be doubled or trebled.

The publication is a very valuable source reference book for schools and colleges or one interested in the oil and gas geology of Western Canada. In compiling a volume of this sort the author is confronted with the problem of how much or how little to say about each particular area. In some cases more information would have been a considerable help, while in other instances too much space has been given to areas drilled on very little or poor geological data. Reliable well-log information is one of the outstanding features of this second edition. A publication of this kind should be accompanied by an up-to-date areal geological map. "Oil and Gas in Western Canada" will be a necessary volume in every geological library of Western Canada.

THEODORE A. LINK

CALGARY, ALBERTA
February 15, 1934

The Principles of Historical Geology from the Regional Point of View. By RICHARD MONTGOMERY FIELD. 283 pp., 10 pls., 108 figs. Paper, 6×9. Princeton University Press, Princeton, New Jersey (1933). $3.50.

Probably the most difficult thing for the average geologist is to obtain a regional understanding of what has taken place in the area with which he works. There are chiefly two reasons why this is so: (1) historical geology as it is taught in the various universities mentions this phase very briefly; (2) the average geologist who has to gain his livelihood by his profession does not have the time or the money with which to investigate the stratigraphic sequence in adjoining states or countries. There is little that can be done about the second reason, as it is something for the individual to work out. Concerning the first reason, the author proposes to alter the present method of teaching and has the following to say in behalf of his book, which is to be used as an advanced text in historical geology.

> The author's interpretation of the existing conditions in the teaching of historical geology is that we are attempting to do too much in the time allowed, and that we are losing sight of the main problem, which is to try to help the student to understand how the history of the earth has been deciphered. Our principal object should be to initiate the student in the technique of the stratigrapher, and thus to afford the student a better opportunity of testing for himself the bases of the geologist's interpretations. As an essential step in this direction, we must minimize the biological aspect of historical geology and consider the history of the earth from a regional point of view. Such a text requires a complete change from a rigid period-by-period treatment. This book has, therefore, been arranged in two Parts. Part I treats of the principles of historical geology, and more particularly of the technique used by the geologist in attempting to discover the geologic history of a region. Part II contains a series of elementary descriptions of geological provinces, selected in the ascending order of their structural complexity.

Part I is divided into three chapters. Chapter I takes up the history of geology with especial emphasis upon stratigraphy. Chapter II deals wholly with sedimentary rocks. Definitions of the various types of sediments are presented and the conditions under which they are deposited are described. One point under the effect of climate upon deposition is brought out and repeated throughout the book. Quoting from p. 48:

> Aridity is shown by the preponderance of aeolian sediments, or red sediments which demonstrate that relatively widespread periods of aridity precede conditions of continental glaciation.

The evidence for aridity as indicated by red beds is not demonstrated by present conditions. Twenhofel, in his *Treatise on Sedimentation*, states that red beds originate under moist and warm conditions and that arid climates produce light colors. In examining desert deposits the reviewer has not observed red beds being formed anywhere in the United States unless they are derived from pre-existing red beds. Also the reviewer is not aware of widespread aridity preceding the Pleistocene in North America. On p. 48, the Triassic is shown as having maximum aridity, yet no glaciation seems to follow in it or in the Jurassic. Chapter III, on the technique of correlation, is very concise and is well worth repeated reading. Nine fundamental principles are presented upon which the art of correlation is based (p. 52):

> (1) The law of superposition. (2) Correlation by lithology. (3) Correlation by paleontology. (4) Index or key formations. (5) The principle of facies. (6) The significance of unconformities. (7) The law of cross-cutting relationships. (8) The significance of metamorphism. (9) The problem of deformation and orogenies.

One very good point is brought out under No. 6, which calls attention to the fact that the degree of angular unconformity does not indicate the length of the time interval.

Part II presents its material in a way which is reminiscent of Willis T. Lee's *Stories in Stone*. Each chapter is very readable and interesting. Chapter IV describes the Grand Canyon region. There are several facts presented which are not qualified by field evidence or existing literature. On p. 93 a disconformity is drawn within the Wingate sandstone which separates the Upper Triassic from the Jurassic. This is the first time that the reviewer has seen this in print and he believes that reasons should be set forth explaining this disconformity. In connection with the contact between the Supai and Hermit formations, the reviewer has observed a pronounced unconformity separating these formations in the walls of the Grand Canyon. This unconformity is not recognized by the author, who classifies the contact as transitional. It is also interesting to note that on p. 104 the term "reef" is further extended to include fossiliferous bedded limestones and as a result the Kiabab limestone is described as a bedded reef. Chapter V describes the Niagara Falls region. Chapter VI takes up the Appalachians. On p. 146 the St. Peter sandstone is stated to be of late Canadian age. This is not in accord with the generally accepted age of the St. Peter, which, in the Mid-Continent, is believed to be of Ordovician age. There are sandstones in the upper Canadian portion of the Arbuckle limestone which resemble the St. Peter and this has doubtless led the author to make the above correlation in the east. Chapter VII describes the northwest highlands of Scotland. Chapter VIII takes up the complex geology of the Alps. While this chapter is well written, the reviewer believes that it is much too brief for so complex a problem and should be made longer. As written, it is the shortest chapter in the book. Chapter IX presents a running account of a party of geologists in Yellowstone Park and the Big Horn Basin region. This description is similar to accounts of the field trips of the Kansas Geological Society. In the first part of each chapter in Part II a brief historical sketch is given of the geological work up to the present time. As a whole, the book has few typographical errors and it should be a handy reference for any geologist to have in his library.

ROBERT ROTH

TULSA, OKLAHOMA
March 9, 1934

"The Geology of Texas," Volume I, "Stratigraphy." By E. H. SELLARDS, W. S. ADKINS, and F. B. PLUMMER. *Univ. Texas Bull. 3232* (1933). Bureau of Economic Geology, Austin, Texas. 1,007 pp., 10 pls., 57 figs., map. 6.5×9 inches. Price $4.00.

To co-ordinate the geological data of an area exceeding a quarter million square miles is a formidable undertaking under any circumstances. When it is considered that Texas comprises several diverse geologic provinces and probably includes more unsolved problems than any other part of the United States, the magnitude of the task increases. Added to the enormous scope of the surface evidence is the information obtained from many thousand oil wells which have been drilled in the state.

One of the most serious handicaps with which the Texas geologist has to

contend is the multiplicity of formation names which have attained more or less general usage, involving the literature in a network of nomenclature that almost precludes intelligent usage. In attempting to bring order out of this choas the present volume has had to make use of 165 formation names, after disposing of a much greater number of obsolete terms. The immensity of this effort can be better understood when it is stated that for the Upper Pennsylvanian of north-central Texas alone 120 member, formation, and group names occurring in the literature have had to be relegated to their proper position in the geologic column. The authors have concentrated on the presentation of an orderly and comprehensive geologic history, leaving much of the detailed lithologic description to other publications.

Part I, written by E. H. Sellards, treats of the pre-Paleozoic and Paleozoic systems in Texas. An introductory résumé of the history of geologic exploration is followed by a general statement of the relationship of lands and seas in the region throughout geologic time.

Pre-Cambrian rocks crop out in three widely separated areas and have been encountered by drilling in four other areas. The marked difference in the various occurrences have required their separate discussion and the use of distinct formation names in each case. The structural conditions responsible for the exposure of these old rocks are described and an interpretation is given of their underground position and relationship wherever well records have furnished such information.

The Paleozoic systems are taken up in order and described in each of the several scattered areas in which they crop out. It is one of the major accomplishments of this book that the many formational units present have been fitted into a complete mosaic in which the multitudinous parts have blended into an intelligible picture.

It is especially true of the Paleozoic that a comprehensive understanding of the geologic history of Texas has been made possible only by the painstaking study and thoughtful interpretation of an immense amount of subsurface data obtained from the thousands of wells which have been drilled. By this means alone a great Paleozoic geosyncline, later involved in a massive overthrust extending in a sweeping arc of almost 600 miles from the Ouachita uplift of Oklahoma to the Marathon uplift of the Trans-Pecos, has been recognized and interpreted, although completely masked by hundreds of feet of superincumbent younger sediments. A list of wells which have penetrated the Paleozoic of the Llanoria geosyncline is given with information as to the nature of the rocks encountered. A table of subsurface data furnished by wells which have entered the pre-Pennsylvanian will serve as a valuable reference. Part I is concluded by illustrations of some of the Paleozoic index fossils.

The Mesozoic systems in Texas constitute Part II, which was written by W. S. Adkins. The broad areas of almost continuous outcrop and the relatively slight deformation which characterize the Triassic and Cretaceous beds of Texas have made the problems of correlation and geologic history much simpler than was the case with the older rocks. As a result it has been possible to give a much more detailed description of the lithologic and faunal character of the Mesozoic rocks than was permissible for the Paleozoic. The numerous facies presented in various parts of the state are well described; distinctive faunal zones are traced over wide areas and a logical correlation of the many members has been made. The more significant subsurface data are given. This

is by far the most comprehensive and satisfactory treatment of the Texas Mesozoic that has ever been presented and concisely summarizes our entire store of present knowledge of the subject.

Part III, by F. B. Plummer, discusses the Cenozoic systems in Texas. A vast amount of geologic investigation is being done in the areas underlain by rocks of these systems and considerable progress is being made in the correlation and interpretation of the results of that work. Mr. Plummer has embodied a large part of the recent work in his discussion, although many of the correlations are still in doubt, and unsolved problems by the score remain to perplex the field geologist. Many groups of sediments which heretofore have had little detailed treatment are described by component members and formations. The lithologic characters, faunal content, areal distribution and geologic history are described carefully and illustrated by excellent figures. This is an invaluable compendium of our present knowledge of the Cenozoic of Texas.

Part IV, a Bibliography and Subject Index of Texas Geology, is by no means the least valuable part of the book. More than 1,800 titles are listed, and the subject index has been compiled in such a way as to make the vast bulk of our unwieldy literature most readily usable.

In a work of the magnitude of this volume, covering such a diversity of subjects, it is inevitable that errors will be included. The well informed geologist will find them here, but they are sufficiently rare to have little effect on its value. Many subjects are not treated as fully as might be desired, but on the whole excellent judgment has been used in condensing the discussion to practical limits without omitting vital information. Every geologist interested in Texas will find this book eminently useful. Our understanding of the magnitude of the work remaining to be done and our knowledge of the information already available have been materially increased by its publication.

ED. W. OWEN

SAN ANTONIO, TEXAS
March 9, 1934

RECENT PUBLICATIONS

GENERAL

Das Schrotbohren (Cable-Tool Drilling), by Josef Kern. 178 pp., 58 figs. 7.75×5.375 inches. Ludwig Nüssler, Leoben (Steiermark), Austria (1933). Paper, R M. 1.5; cloth, R M. 5.5.

"Use of Airplanes in Mining and Petroleum Operations," by Hugh M. Wolflin. *U. S. Bur. Mines Inform. Cir. 6767* (February, 1934). 27 mimeogr. pp. Abstracted from U. S. G. S. Bulletin manuscript by Charles Will Wright.

Proc. World Petroleum Congress (London, 1933), Vol. I (1934), "Geological and Production Sections." Edited by A. E. Dunstan and George Sell. Approx. 100 major articles on the program of the Congress organized by the Institution of Petroleum Technologists held at the Imperial College of Science and Technology, South Kensington, London, July 19–25, 1933. 592+xxiv pp., illus. Cloth. Outside dimensions, 9×11.25 inches. Address

inquiries to Joint Editors, World Petroleum Congress, Aldine House, Bedford Street, London, W.C. 2. Price: to members of the Congress, £1, 10s; to non-members, £1, 15s. Regular non-member price, if ordered through W. S. Malloy, 8–10 Bridge Street, New York, N.Y., $8.85 plus 25 per cent duty.
Vol. II (1934), "Refining, Chemical and Testing Section." Same editors. 954+xxvi pp. Same binding and size. Price, £2, 5s ($11.45 plus duty).
Vols. I and II together. Price, £3, 13s, 6d ($18.75 plus duty).
Sectional Vol. A, "Geological Significance of the Regional Distribution of Oilfields." 82 pp. Price, 10s, 6d ($2.65).
Sectional Vol. B, "Modern Developments in Geological Exploration," Pt. I, "Geophysics." 112 pp. Price, 10s, 6d ($2.65).
Sectional Vol. C, "Modern Developments in Geological Exploration," Pt. II, "Aeroplane Reconnaissance and Photography, Evaluation of Surface Evidences of Petroleum, Field Methods: Geological Aspects of Oilfield Development." 154 pp. Price, 12s, 6d ($3.15).

Outlines of Physical Geology, by Chester R. Longwell, Adolph Knopf, and Richard F. Flint. John Wiley and Sons, Inc., 440 Fourth Avenue, New York (1934). 356 pp., 157 figs. 6×9 inches. Cloth. Price, $3.00, net.

Historical Geology, by Walter A. Ver Wiebe. 162 pp., 206 figs. Photolithoprint reproduction of author's manuscript by Edwards Brothers, Inc., Ann Arbor, Michigan (1934). 8.25×10.75 inches. Paper.

GERMANY

"Zur Petrographie brennstoffführender Sedimente Deutschlands" (On the Petrography of Sediments in Germany Containing Combustible Materials), by Heinrich Müller. *Centralbl. f. Min.*, etc. (Hamburg, 1934), Abt. B, No. 2, pp. 49–56.

"Sedimentpetrographie und Geologie" (Sedimentary Petrography and Geology), by Heinrich Müller. *Zeits. der Deutsch. Geol. Gesell.* (Hamburg, 1933), Band 85, Heft 9, pp. 719–20.

TEXAS

"Bureau of Mines Reports Summary of Analyses of Typical Crude Oil from East Texas and Adjoining Fields," by E. L. Garton and R. E. Thurn. *U. S. Bur. Abstr. of Bur. Pub.* (February 12, 1934). 2 mimeogr. pp. and 3 tables.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 18, NO. 4 (APRIL, 1934), PP. 558-559

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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Memorial

ARLES FRANCIS MELCHER

Arles Francis Melcher died in the Flower Hospital, Tulsa, Oklahoma, in the early morning hours of October 21, 1933. His death was caused by complications resulting from a fall that occurred last summer during a visit to his father's farm near Union Star, Missouri.

Dr. Melcher was born on May 29, 1883, near Moweaqua, Shelby County, Illinois. From 1903 to 1909, he attended Central College, Fayette, Missouri, receiving a B.S. degree in 1907 and an M.S. degree in 1909. The years 1909-1911 were spent in the post-graduate school of the University of Chicago. In 1923, he received the degree of Ph.D. from George Washington University, Washington, D.C.

After leaving the University of Chicago, he became a member of the scientific staff of the Division of Weights and Measures of the United States Bureau of Standards. On March 1, 1913, he began his duties as assistant physical geologist in the Physical Laboratory of the United States Geological Survey. Promoted through the various grades, he received the appointment of associate geophysicist on July 1, 1924, and on February 28, 1925, he resigned this position to accept an appointment as research physicist in charge of the physical and recovery section of the Marland Oil Company, Ponca

City, Oklahoma. Following the discontinuation of this work on February 20, 1928, Melcher established a private laboratory at Tulsa, Oklahoma, and later, branches were established at Bradford, Pennsylvania, and Oklahoma City, Oklahoma. Associated with him in this work were Paul M. Phillippi at Bradford, and Gilbert Noble at Tulsa and Oklahoma City.

Dr. Melcher's first publication in geophysics was on the change of density of sulphur with rupture. The results of this research formed the basis of a paper—"Note on Mean Density of Fractured Rocks"—by the late Dr. George F. Becker, at that time geologist in charge of the Division of Chemical and Physical Research of the Geological Survey. Shortly after the publication of these papers, there occurred an incident which was the turning point in Melcher's career. It so happened that Dr. G. B. Richardson of the Survey staff made some inquiries in regard to the possibility of making porosity determinations of some Appalachian oil sands. The specimens were given to Melcher for trial tests. He immediately manifested the keenest interest in this problem, and thereafter porosity determinations, more than any other problem, dominated his scientific career. His papers on the subject have definitely established new and advanced precision methods in this important field of research. Before leaving the Geological Survey, he did considerable work in coöperation with the United States Bureau of Mines and the Bureau of Internal Revenue, Treasury Department, Washington, D. C.

Owing to the difficulty of obtaining rock samples suitable for porosity tests, it was quite natural that Melcher should attempt the design of a core drill. His first attempt in this field was the design of a bit for use with a standard rig. It was patented under date of August 24, 1926 (No. 1597325).

His membership in scientific societies includes the following: The American Association of Petroleum Geologists; American Physical Society; Washington Philosophical Society; Geological Society of Washington; Oklahoma Academy of Sciences; American Association for the Advancement of Science; American Petroleum Institute; and the National Geographic Society. He was chairman of the committee on texture of oil rock of the National Research Council, and also, chairman of the committee on laboratories and apparatus of the Institute of Mining and Metallurgical Engineers.

Besides his wife, Effie A. Bills Melcher, the deceased is survived by his mother, Sarah G. Melcher; a brother, Charles Melcher; a sister, Mrs. Chester L. Buoy; a twin son and daughter, William L. and Miriam F., age 19; and a son, Lewis A., age 20.

Quite apart from his scientific achievements, which were highly creditable, Melcher's passing will be mourned by a host of friends who will long remember his kindly joyous disposition and his unbounded devotion to his family.

BIBLIOGRAPHY OF ARLES FRANCIS MELCHER

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C. E. Van Orstrand

Washington, D. C.
March 10, 1934

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGIGTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

DOUGLAS JOHNSON, professor of physiography in Columbia University, New York, delivered the following public lectures at the Rice Institute, Houston, Texas, March 13, 14, and 15: "The Grand Canyon District"; "Evolution of the Atlantic Shoreline"; and "A Physiographic Traverse of the United States."

D. DALE CONDIT, consulting geologist, 11,140 Montana Avenue, West Los Angeles, California, sailed to Australia early in March for the appraisal of oil possibilities throughout that country.

Recent speakers before the Tulsa Geological Society were: D. C. NUFER, Carter Oil Company, Tulsa, "Stratigraphy of the Ardmore Area, Oklahoma"; and L. A. JOHNSTON, Sinclair-Prairie Oil Company, Tulsa, "Pre-Pennsylvanian Stratigraphy of the Hollow Area in Kansas."

S. A. THOMPSON, of the Magnolia Petroleum Company, Shreveport, Louisiana, gave a paper, "The Fredericksburg Division with Special Reference to North-Central Texas," before the Shreveport Geological Society, March 2.

E. J. P. VAN DER LINDEN, newly elected secretary-treasurer of the Alberta Society of Petroleum Geologists, Calgary, Alberta, reports the following list of papers presented at the sixth annual meeting: (1) "Pekisko Hills Structure," by R. Willis; (2) "Fault Problems in Brazeau District," by B. F. Hake, R. Willis, and C. Addison; (3) "The Cutbank Field," by J. S. Irwin; (4) "The Geology of Southern Saskatchewan," by J. O. G. Sanderson; (5) "A Dead-Weight Gauge," by H. M. Hunter; (6) "Professional Fees," by R. V. Johnson; (7) "Report on the Dowling Memorial," by B. L. Thorne; (8) "Petroleum at Century of Progress," by T. A. Link.

The scientific library of the late U. S. GRANT, consisting of about 1,500 bound and 4,000 unbound volumes, has been presented by Mrs. Grant to the department of geology and geography of Northwestern University, where Professor Grant was head of the department for 33 years preceding his death in September, 1932.

The Geological Society of Switzerland will celebrate its fiftieth anniversary in September. The society was formed on September 11, 1882. For several reasons the celebration was not held in 1932. Several excursions in the Alps are being planned and geologists from other countries are invited. Details may be requested from the president, Maurice Lugeon, Laboratoire de Géologie, Université Lausanne.

The San Antonio Geological Society, San Antonio, Texas, has elected the following officers for the new year beginning March 25, 1934: president,

T. J. Galbraith, California Company, San Antonio, Texas; vice-president, A. E. Getzendaner, Gulf Production Company, Corpus Christi, Texas; secretary-treasurer, T. R. Banks, Magnolia Petroleum Company, San Antonio, Texas; member of executive committee, Stuart Mossom, consulting geologist, San Antonio, Texas.

The following officers of the Petroleum Division of the American Institute of Mining and Metallurgical Engineers have been elected for the year: chairman, H. D. Wilde, jr., Humble Oil and Refining Company, Houston; associate chairman, V. H. Wilhelm, The Texas Company, Los Angeles; secretary-treasurer, A. E. Stephenson, Missouri School of Mines, Rolla. Harry H. Power, Gypsy Oil Company, Tulsa, is vice-chairman of production engineering; Frank A. Herald, consulting geologist, Fort Worth, is vice-chairman of production review; and F. B. Plummer, University of Texas, Austin, is vice-chairman of engineering research.

E. B. Stiles is with the Tidewater-Seaboard Oil Company at Palestine' Texas.

George S. Buchanan is geologist for the Adams Louisiana Corporation, 2302 Esperson Building, Houston, Texas.

Marvin Lee, consulting petroleum geologist of Wichita, has announced the removal of his office to 800 Bitting Building, Wichita, Kansas, in connection with his duties as technical adviser to the Oil Proration Division of the Kansas State Corporation Commission.

Cary P. Butcher, president of the West Texas Geological Society, San Angelo, Texas, asked for agreement of geologists in naming West Texas oil fields, in a recent talk before the society.

Dana M. Secor has changed his address from the Houston Oil Company, Petroleum Building, to Skelly Oil Company, Esperson Building, Houston, Texas.

E. B. Wilson, geologist with the Sun Oil Company, has been transferred from San Antonio to Tyler, Texas. His mail address is Box 807.

William H. Butt, formerly of Apartado 10, Matanzas, Cuba, may now be addressed at Route 2, Asheville, North Carolina.

H. J. Hawley, geologist with The California Company, has been transferred from San Francisco, California, to Dallas, Texas, with offices in the Tower Petroleum Building.

E. E. Lindeblad has changed his address from 3207 N. Blackwelder, Oklahoma City, Oklahoma, to Box 566, Little Rock, Arkansas.

John A. McCutchin, Shell Petroleum Corporation, has been transferred from McPherson, Kansas, to Pampa, Texas, as district exploitation engineer.

Djevad Eyoud, consulting geologist, of San Antonio, Texas, reports an interesting trip down Tigris River on a raft, pulling to shore at night, and sleeping on the sands. Harold F. Moses, of Ankara, Turkey, accompanied him.

J. N. TROXELL, of The Texas Company, has been transferred from Houston to Tulsa, where he will assume the duties of the division geologist for the Oklahoma-Kansas district.

FRANK C. ADAMS, formerly with The Texas Company, Houston, Texas, is now with the Gem Oil Company, 1506 Esperson Building, at Houston.

A. M. MEYER, of the Atlantic Oil Producing Company, has been transferred from Beeville, Texas, to 710 Bitting Building, Wichita, Kansas.

ADDISON Young has changed his address from 1314 Second National Bank Building, Houston, Texas, to General Delivery, Rio Grande City, Texas.

FRED A. DAVIES, of The California Company, may be addressed at the Bahrein Petroleum Company, Ltd., Bahrein Islands, Persian Gulf.

A. P. ALLISON has recently been transferred from the land department of the Sun Oil Company to the geological department, to do subsurface work in the Houston office.

ARNOLD C. DAHL has changed his address from the Shell Petroleum Corporation, McPherson, Kansas, to the Wolverine Petroleum Corporation, Box 219, Avant, Oklahoma.

M. MILSTEIN, mining engineer and geophysicist, formerly at Bucareli 128, Mexico, D. F., Mexico, left recently for Australia and may be addressed at Head Post Office, Sydney, N. S. W.

GLENN D. ROBERTSON, of Los Angeles, California, has accepted a position with the Shell Petroleum Corporation and at present may be addressed at Box 7, Buffalo, Texas.

V. F. MARSTERS, geologist, formerly of Kansas City, Missouri, and later of Winnsboro, Texas, is now located at Princeton, Kentucky, where he is engaged in geological work.

GEORGE R. WOOD, formerly of Hampton, Iowa, is now at Ultramar S. A. P. A., 778 Calle Chile, Buenos Aires, Argentina, S. A.

H. E. REDMON, geologist for The National Refining Company, formerly at Tulsa in charge of the office for the last three years, is now with the same company at 206 Mid-Continent Building, Eldorado, Kansas, where the company recently moved the geological department.

IRA A. WILLIAMS, consulting geologist, of Portland, Oregon, died January 22, at the age of 58.

Officers of The Geological Society of America for 1934 are: president, W. H. COLLINS, Ottawa, Canada; secretary, CHARLES P. BERKEY, 419 West 117th Street, New York City; treasurer, EDWARD B. MATHEWS, Baltimore, Maryland.

J. LAUER STAUFT, geologist with the International Petroleum Company at Talara, Peru, was killed in an explosion early in March.

The group photograph taken at the Jackson Street entrance of the Baker Hotel, Dallas, during the nineteenth annual convention of the Association, may be ordered at $1.00 per copy by writing to CHARLES B. CARPENTER, secretary-treasurer of the Dallas Petroleum Geologists, 515 Federal Building, Dallas, Texas.

R. L. McLAREN, of Golden, Colorado, has completed a graduate course in seismic, magnetic, and torsion-balance geophysical prospecting at the Colorado School of Mines.

The officers of The Alberta Society of Petroleum Geologists at Calgary, Alberta, are: president, G. R. ELLIOTT; vice-president, J. G. SPRATT; secretary-treasurer, E. J. P. VAN DER LINDEN; and business representative, S. E. SLIPPER.

G. C. POTTER has an office as consulting geologist at 328 Milam Building, San Antonio, Texas.

WALTER ENGLISH addressed the Pacific Section of the Association, March 16, 1934, on the subject, "An Analysis of the Present Situation in the East Texas Oil Fields."

RAYMOND C. MOORE spoke before the Tulsa Geological Society, March 20, 1934, on "Differentiation of the Permian and Pennsylvanian Sediments."

A. D. MILLER, of the Louisiana State Conservation Department, gave a paper entitled, "The Converse Oil Field, Sabine Parish, Louisiana," before the Shreveport Geological Society, March 16, 1934.

The annual meeting of the Appalachian Geological Society was held February 24, 1934, in the Old Tech Building at the University of Cincinnati, Cincinnati, Ohio. Papers on western Kentucky oil fields were read and discussed. The annual spring field trip was set for May 3–6, beginning at the Brown Hotel, Louisville, Kentucky. The itinerary included visits to the asphalt deposits near Hardinsburg, the oil fields near Owensboro, the Rough Creek fault zone near Sebree, the western Kentucky coal basin, feldspar dikes, and Chester fossil fields.

The Association of American State Geologists held its regular annual meeting and conference with the Federal officials in Washington, D.C., on February 22–23. The following officers were elected for the ensuing year: president, GEORGE C. BRANNER, Arkansas; secretary, ARTHUR BEVAN, Virginia; third member of executive committee, RAYMOND C. MOORE, Kansas.

L. DUDLEY STAMP, of the London School of Economics, University of London, has been in America during the past several months in connection with problems of the use of waste or idle lands. In March he visited the Trinidad oil fields. He may be addressed in care of the American Geographical Society, Broadway at 156th Street, New York.